Guidebook on Methods to Estimate Non-Motorized Travel: Supporting Documentation

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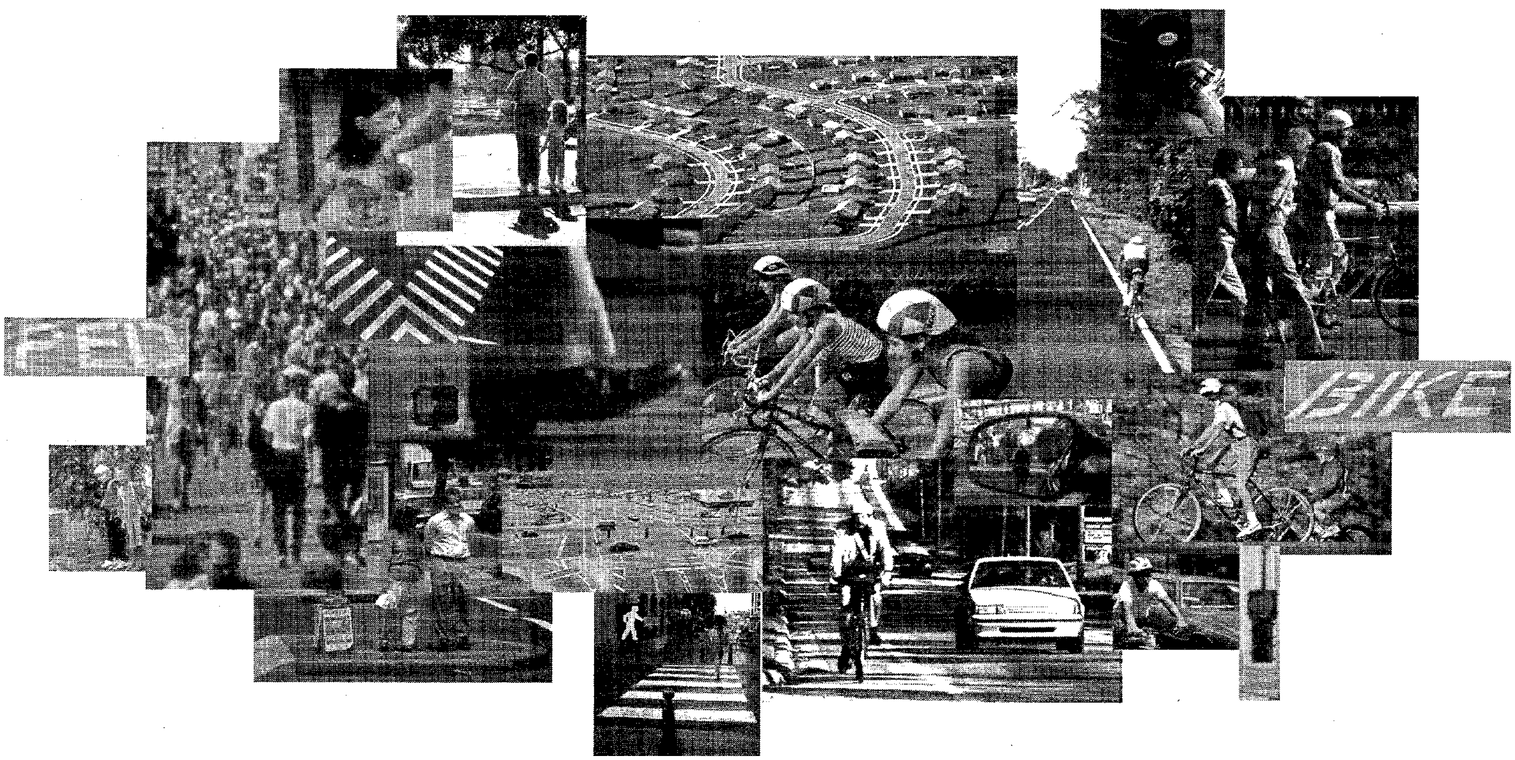

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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McLean, VA 22101-2296

FOREWORD

This two-volume guidebook describes and compares the various methods and tools that can be used to forecast non-motorized travel demand or that otherwise support the prioritization and analyses of bicycle and pedestrian facilities. The guidebook is intended to be used by bicycle and pedestrian planners, technical staff, researchers, advocates, and others who may wish to estimate bicycle and pedestrian travel demand or to prioritize bicycle and pedestrian projects.

This second volume, *Supporting Documentation,* gives details on each method, including purpose, structure, input / data needs, assumption, and real world applications. This volume contains an extensive annotated bibliography of reference on demand forecasting methods, supporting tools and techniques, and factors influencing the choice to walk or bicycle, as well as potential contacts in this field. The other volume, *Overview of Methods,* provides an overview of each of nineteen methods appropriate for forecasting and / or understanding pedestrian and bicycle travel demand.

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Director, Office of Safety R&D

NOTICE

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16. Abstract

This guidebook provides a means for practitioner to better understand and estimate bicycle and pedestrian travel and to address transportation planning needs. The guidebook describes and compares the various methods that can be used to forecast non-motorized travel demand or that otherwise support the prioritization and analyses of non-motorized projects. These methods are categorized according to four major purposes: (1) demand estimation; (2) relative demand potential; (3) supply quality analysis; and (4) supporting tools and techniques. Discrete choice models, regional travel models, sketch plan methods, facility demand potential, bicycle compatibility measures, and geographic information systems are among the methods and tools described.

Overview of Methods provides a concise overview for each available method, including some typical applications, pros and cons, and a quick reference guide on ease of use, data requirements, sensitivity to design factors, and whether widely used. In addition, it discusses general issues for consideration in forecasting non-motorized travel demand, such as the dimension of travel behavior and factors influencing bicycling and walking, and identifies future needs in this area.

Supporting Documentation provides substantially more detail on the methods including purpose, structure, input/data needs, assumptions, and real-world applications. It also contains an extensive annotated bibliography of references on demand forecasting methods, supporting tools and techniques, and factors influencing the choice to walk or bicycle, as well as potential contacts in this field.

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Unclassified	Unclassified	170	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.636	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1.0 Introduction

❑ 1.1 Overview

This document is the second volume of the two-volume *Guidebook on Methods to Estimate Non-Motorized* Travel where the first volume, Overview *of Methods,* provides a concise overview of available methods for predicting future levels of bicycle and pedestrian travel or "travel demand." The Overview *of Methods* also discusses general issues for consideration in forecasting demand for non-motorized travel. This volume, the Supporting *Documentation,* provides substantially more detail on the methods described in the guidebook and identifies sources and real-world applications of the methods.

This volume is organized as follows:

- **Section 2.0 (Documentation of Methods) —** An in-depth, structured description and evaluation of each method, including multiple variations on some methods as well as real-world applications.

- **Section 3.0 (Bibliography) —** An annotated bibliography of references on demand forecasting methods, supporting tools and techniques, and factors influencing the choice to walk or bicycle.

- **Section 4.0 (Contacts) —** A list of individuals and organizations contacted in developing this guidebook.

The contents of the Overview *of Methods* include:

- **Section 1.0 —** A discussion of the purpose of the guidebook and the importance and uses of forecasting bicycle and pedestrian travel demand.

- **Section 2.0 —** An introduction to non-motorized travel demand forecasting, including ways in which travel behavior can change, general approaches to travel demand forecasting, factors specifically influencing bicycle and pedestrian travel, and differences in forecasting bicycle vs. pedestrian travel.

- **Section 3.0 —** An introduction to 11 classes of methods and a one-page overview of each which includes a description, typical applications, advantages, and disadvantages. Section 3.0 also contains a summary of key characteristics and uses of each method as well as a guide to choosing an appropriate method for **a** specific purpose.

- **Section 4.0 —** A summary of the guidebook and a discussion of the limitations of existing forecasting methods and future research needs for improving non-motorized demand forecasting.

1.2 Purpose of the Guidebook

The need for improved conditions for bicyclists and pedestrians has received increasing attention in recent years in transportation planning circles. Planners are recognizing a growing popular interest in bicycling and walking for health and recreation, the desire to promote alternatives to automobile travel for environmental reasons, and the need to provide safe and convenient travel options for the entire population. At the same time, the question of how many people will actually use new or improved bicycle and pedestrian facilities is gaining interest and importance. Planners and policy makers need to be convinced that the benefits of improvements are worth the costs. Furthermore, they want to know where to spend limited resources to get the most "bang for the buck" as measured by benefits to users.

This guidebook was developed in response to the need to predict bicycle and pedestrian or "non-motorized" travel.[1] The guidebook is intended to provide a means of addressing the following related questions:

- If we build a new bicycle or pedestrian facility, how many people will use it?
- If we improve an existing facility or network, how many additional people will choose to walk or bicycle?
- What types and combinations of improvements will have the greatest impact on increasing non-motorized travel?
- How will improvements to non-motorized travel conditions affect motor vehicle use?

The guidebook describes and compares the various methods that have been developed to predict future levels of bicycle and pedestrian travel, i.e., travel demand. The guidebook also discusses other quantitative methods that support demand forecasting but do not actually predict future demand. These include (1) analyses of the potential market for bicycling and walking; (2) "level of service" measures and "environment factors" that describe the quality of the supply of bicycle and pedestrian facilities; and (3) supporting tools and techniques such as Geographic Information Systems (GIS) and preference surveys. The guidebook is intended to be used by bicycle and pedestrian planners, technical staff, researchers, advocates, and others who may wish to apply these methods to estimate bicycle and pedestrian travel demand or to prioritize bicycle and pedestrian projects.

[1] Bicycling and walking are the most common forms of non-motorized travel in most countries and ***the term "non-motorized" is used here to refer collectively to bicycle and pedestrian travel.*** Nevertheless, the term "non-motorized" could also refer to many other forms of travel such as rollerblading, skateboarding, or horseback riding. The methods discussed in this document may be applicable to these other forms of non-motorized travel although specific applications have not been identified.

1.3 Research Methodology

The guidebook is based on an extensive international review of both published and unpublished sources. Most of the methods were developed in the United States, Canada, and Europe, but examples are also included from Japan, Australia, and South America.

Members of the research team conducted an extensive outreach effort to identify research activities (both past and present), methods, and ideas for the project. This consisted of a networking effort that began with people who are well known in the field of bicycle and pedestrian planning and other individuals who are known to the research team. Simultaneous to the direct networking, the Internet was used as a means of outreach through a variety of discussion lists. All told, more than 65 contacts were made. These included other consulting firms, research and/or cycling organizations in foreign countries, practitioners, and individuals. The complete list of contacts made or targets of outreach is presented in Section 4.0.

In addition to the networking effort, a literature review was conducted to identify relevant published sources. It should be noted that not all of the methods discovered in this literature review are of recent vintage. The rise of the energy crisis and the environmental movement in the 1970s led to considerable interest and research into bicycle and pedestrian planning issues during this period. As an example, in 1978 the Federal Highway Administration published a three-volume *Pedestrian Planning Procedures Manual* (Kagan, Scott, and Avin, 1978). The manual outlined a 27-step process for forecasting pedestrian travel demand and prioritizing pedestrian projects in central business districts and other large activity centers. At the same time, discrete choice modeling techniques were pioneered and developed for the purposes of forecasting travel. These techniques were applied specifically to forecasting bicycle travel in a number of studies conducted in the late 1970s and early 1980s.

As relevant methods were identified from the networking and literature review efforts, they were documented in a database. The final version of this data base is presented here as Section 2.0, "Documentation of Methods." This data base served as a structure for an organized discussion and evaluation of each method, and also served as the basis for categorizing and describing the methods as presented in the guidebook.

1.4 Overview of Methods

Nineteen method entries were completed in the data base. For purposes of the discussion in the guidebook, the entries were grouped into 11 classes of methods having similar characteristics. These were further grouped according to the four major purposes of the methods: demand estimation, relative demand potential, supply quality analysis, and supporting tools and techniques. Table 1.1 describes the four major purposes and 11 classes of methods. Table 1.2 shows how the 11 classes of methods correspond to the 19 method entries contained in Section 2.0.

Some of the entries in section 2.0 describe one specific method, as developed by a particular practitioner, while others contain descriptions of two to four similar methods. Decisions as to whether to group methods of the same type in one entry or to treat them in separate entries were primarily based on the similarity of the methods and on the length of the discussion for each. Treatment of some methods in separate entries is not meant to imply that a greater importance is attached to that specific method, and is not meant to endorse the use of those methods over others.

Table 1.1 Categorization of Available Methods.

Purpose	Method	Description
Demand Estimation		**Methods that can be used to derive quantitative estimates of demand.**
	Comparison Studies	Methods that predict non-motorized travel on a facility by comparing it to usage and to surrounding population and land use characteristics of other similar facilities.
	Aggregate Behavior Studies	Methods that relate non-motorized travel in an area to its local population, land use, and other characteristics, usually through regression analysis.
	Sketch Plan Methods	Methods that predict non-motorized travel on a facility or in an area based on simple calculations and rules of thumb about trip lengths, mode shares, and other aspects of travel behavior.
	Discrete Choice Models	Models that predict an individual's travel decisions based on characteristics of the alternatives available to them.
	Regional Travel Models	Models that predict total trips by trip purpose, mode, and origin/destination and distribute these trips across a network of transportation facilities, based on land use characteristics such as population and employment and on characteristics of the transportation network.

Table 1.1 Categorization of Available Methods (continued)

Purpose	Method	Description
Relative Demand Potential		**Methods that do not predict actual demand levels, but which can be used to assess potential demand for or relative levels of non-motorized travel.**
	Market Analysis	Methods that identify a likely or maximum number of bicycle or pedestrian trips that may be expected given an ideal network of facilities.
	Facility Demand Potential	Methods that use local population and land use characteristics to prioritize projects based on their relative potential for use.
Supply Quality Analysis		**Methods that describe the quality of non-motorized facilities ("supply") rather than the demand for such facilities. These may be useful for estimating demand if demand can be related to the quality of available facilities.**
	Bicycle and Pedestrian Compatibility Measures	Measures that relate characteristics of a specific facility such as safety to its overall attractiveness for bicycling or walking.
	Environment Factors	Measures of facility and environment characteristics at the area level which describe how attractive the area is to bicycling or walking.
Supporting Tools and Techniques		**Analytical methods to support demand forecasting.**
	Geographic Information Systems	Emerging information management tools, with graphic or pictorial display capabilities, that can be used in many ways to evaluate both potential demand and supply quality.
	Preference Surveys	Survey techniques that can be used on their own to determine factors which influence demand, and that also serve as the foundation for quantitative forecasting methods such as discrete choice modeling.

Table 1.2 Organization of Methods in Supporting Documentation.

Purpose	Method	Method Number	Corresponding Methods in Supporting Documentation	Page Number
Demand Estimation				
	Comparison Studies	2.1	Comparison Studies	2-1
	Aggregate Behavior Studies	2.2	Aggregate Behavior Studies	2-7
	Sketch Plan Methods	2.3	Bicycle Sketch Plan Methods	2-13
		2.4	Pedestrian Sketch Plan Methods	2-18
	Discrete Choice Models	2.5	Discrete Choice Models	2-28
		2.6	Discrete Choice Models: Route Choice	2-37
		2.7	Discrete Choice Models: Transit Access	2-42
	Regional Travel Models	2.8	Regional Travel Models	2-47
		2.9	Bicycle Travel Models: Quovadis-Bicycle	2-59
		2.10	Bicycle Travel Models: START and TRIPS	2-65
		2.11	Pedestrian Demand Models	2-71
Relative Demand Potential				
	Market Analysis	2.12	Market Analysis	2-76
	Facility Demand Potential	2.13	Latent Demand Score	2-81
		2.14	Pedestrian Potential and Deficiency Indices	2-85
Supply Quality Analysis				
	Bicycle and Pedestrian Compatibility Measures	2.15	Bicycle Compatibility Measures	2-89
		2.16	Pedestrian Compatibility Measures	2-96
	Environment Factors	2.17	Environment Factors	2-101
Supporting Tools and Techniques				
	Geographic Information Systems	2.18	Geographic Information Systems	2-106
	Preference Surveys	2.19	Preference Surveys	2-117

2.0 Documentation of Methods

Demand Estimation:

■ 2.1 Comparison Studies

Descriptive Criteria: What is it?

Categories:

❑ Bicycle •I Pedestrian ⊠ Facility-Level •?J Area-Level

Authors and Development Dates:

Hoekwater (1978); Lewis and Kirk (1997); Wigan (1998)

Purpose:

The simplest form of demand forecasting, comparison studies track bicycle or pedestrian travel levels before and after a change (such as a facility improvement), or compare travel levels across facilities with similar characteristics. The results of a comparison study can be used to predict the impacts on non-motorized travel of a similar improvement in another situation, assuming that all other influencing factors are roughly the same between the two situations.

Two basic types of comparison studies are discussed here:

1. Before-and-after studies. These are based on counts of users both before and after an improvement. The change in users is assumed to be related to the improvement.

2. Similar conditions studies. These studies use counts and/or user survey data from existing facilities, sometimes combined with data on the population in the surrounding area, to estimate the potential number of users on a similar existing or proposed facility. Two examples are documented here:

   Lewis and *Kirk (1997):* To forecast travel on two proposed rail trails, employees at the Central Transportation Planning Staff (CTPS), the regional transportation planning agency for the Boston, Massachusetts metropolitan area, examined a comparable existing rail trail using counts of trail users and travel survey data for area residents.

   Wigan, Richardson, and Brunton (1998) compared the characteristics of users and the surrounding population on two existing facilities in Australia, and identified factors that could account for differences in usage levels on the two trails.

Structure:

Before and After Studies:

These have been widely used in Europe to assess the mode choice impacts of programs to improve bicycle and pedestrian facilities. Some studies have focused on the change in mode split for an urban area as a whole, after a city-wide program of improvements. Others have focused on specific facilities, conducting user counts both before and after an improvement to the facility. An example of the latter is given in Hoekwater (1978), who compared bicycle traffic before and after the addition of bicycle lanes in the Netherlands. In addition to counts on the facility itself, counts were also performed on parallel facilities to attempt to estimate how much traffic was diverted as compared to actual new riders.

Similar Conditions Studies:

Lewis/Kirk: To estimate the potential usage of a proposed rail trail in Massachusetts, planning staff conducted bicycle counts on an existing trail which has characteristics similar to the proposed facility. These counts were then factored based on the ratio of total population within corridors surrounding the two facilities to predict total trips on the proposed facility. Total volumes were distributed throughout the proposed corridor based on the population of communities along the corridor. An alternative method was also applied in which forecasts for the proposed trail were factored by the ratio of bicycle commuting mode share in the two corridors, as determined from census data.

Wigan/Richardson/Brunton: Two existing facilities in Australia were compared: Lower Yarra and Maribrynong trails. A survey of trail users was conducted regarding mode of access to the trail, access distance, personal characteristics, etc. Data on population in the surrounding area were also analyzed using GIS techniques. The characteristics of users and the surrounding population were both used to compare the two trails. The results indicate that the Lower Yarra trail attracts more users from a wider range of distances than the Lower Maribrynong. The authors concluded that with better signage, improved linkages and promotional efforts for the Lower Maribrynong facility, this trail could see higher usage rates, similar to the Lower Yarra trail. The model gives an estimate of the potential users of the Lower Maribrynong trail (see also GIS, Method 1.18)

Calibration/Validation Approach:

Not applicable.

Inputs/Data Needs:

Before and After Studies:

These require counts or mode split data from the facility or area before and after the improvement. Counts should also be obtained from parallel facilities to determine to what extent a change in traffic on a facility is due to diversion as compared to new users. Ideally, counts would also be performed over the same time period in other control areas that are unaffected by the improvements to determine whether traffic levels may have changed for reasons unrelated to the facility addition. Enough counts should be performed so that the statistical significance of any observed change in traffic can be verified.

Similar Conditions Studies:

Lewis/Kirk: The comparison approach requires bicycle counts for the existing facility and population data for the surrounding areas of both the existing and proposed facilities.

Wigan/Richardson/Brunton: The technique uses survey results taken from the VITAL project, which is a continuing household interview survey in Melbourne that covers the origins and destinations of bicycle travel. Another survey was conducted by Melbourne Parks and Waterways (MPW). A third survey questioned only users at the Lower Yarra and Lower Maribrynong trails.

The main inputs that are used from these surveys include:

- Trip length distributions;
- Numbers of patrons from different postal code areas (equivalent to ZIP codes);
- Populations in postal code regions at various distances from the trail; and
- Distances from the trail to the different postcode area centroids.

Potential Data Sources:

Lewis/Kirk: This approach could use localized mode split information to provide better accuracy.

Computational Requirements:

Minimal computations are required.

User Skill/Knowledge:

Minimal skill is needed.

Assumptions:

Unless very carefully designed, comparison studies may not control for other factors unrelated to the facility improvement which may affect usage levels, such as weather conditions on the day of the count, improvements to parallel facilities, etc. Also, the specific factors causing differences in impacts for different facilities may not be readily explained, or may only be described qualitatively. Because of possible differences in the situation, transferring results from one situation to another may lead to incorrect usage forecasts. Therefore, the comparison method is best used in conjunction with a qualitative assessment of environmental factors to gauge an approximate level of impact, rather than for quantitatively predicting an actual change in usage levels.

Wigan/Richardson/Brunton: This technique assumes that the main reason that the two trails have different user rates is because of inadequate signage and connections at the trail with the lower usage rate. The differences in level of usage between two apparently similar trails illustrates why care must be taken in using a simple comparison approach to predict demand.

Facility Design Factors:

Lewis/Kirk and *Wigan/Richardson/Brunton:* This approach requires planners to compare facilities that are similar in type and length.

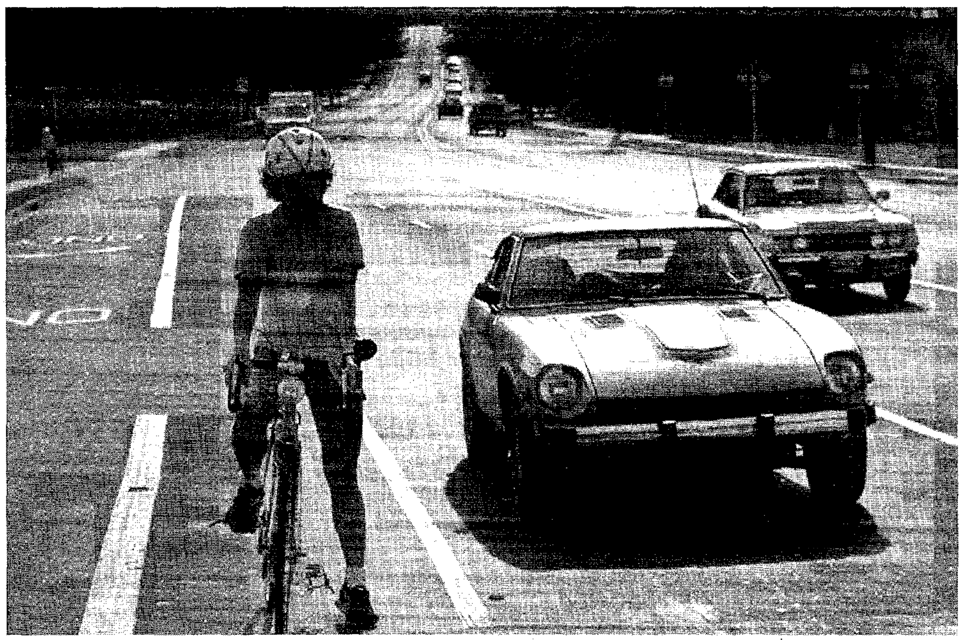

Figure 2.1 A similar conditions study uses data from an existing facility, such as the bike lane shown here, to estimate the potential number of users on a proposed facility.

Output Types:

These methods supply the planner with rough estimates of bicycle usage for proposed facilities.

Real-World Examples:

Hoekwater: Counts of bicycle traffic were performed before and after the addition of bicycle lanes at two locations in the Netherlands. Counts were also performed on parallel facilities to attempt to estimate diversion vs. new riders. In one location, bicycle counts increased by 30 to 60 percent on the route with a slight increase on parallel routes. For a different location, bicycle traffic on the route also increased but there was some decrease on parallel facilities; the authors concluded that roughly two-thirds of the increase in bicycle traffic came from parallel routes and one-third from new trips.

Lewis/Kirk: Bicycle counts from the Minuteman Commuter Bikeway in the Boston area were used to predict the bicycle volumes for the proposed Central Massachusetts Rail Trail Bikeway. Weekend and peak-hour weekday counts were taken at four locations along the 48-km long Minuteman facility. Weekday counts then were estimated by assuming that the peak period represents 10 percent of the daily usage. An average of the four survey sites was taken to obtain a weekday estimate of 1,600 and a weekend estimate of 3,400 users. The population of the Central Massachusetts Bikeway corridor, at 138,556, is 80 percent that of the Minuteman corridor's population of 172,606. Usage estimates for the Central Massachusetts Bikeway, therefore, total 1,280 for the weekdays and 2,720 for the weekends. The volumes then were distributed along the corridor according to population share.

The same approach was used on the Norwottuck Rail Trail, which is at the western end of the proposed Central Massachusetts Bikeway. Weekday bicycle volumes total 700, weekend/holiday volumes total 1,900 and the regional population is 69,000. The surrounding area for the proposed facility has two times the Norwottuck population so the daily estimates total 1,400 per weekday and 3,800 per weekend/holiday.

Wigan/Richardson/Brunton: The Lower Yarra and Lower Maribrynong trails differ in that the latter lacks linkages and promotional opportunities. Since the populations surrounding the two trails are similar as well as each trail's length, the user rates also should be similar. The Lower Maribrynong trail has a significantly higher usage rate. The authors hypothesized that the proportional difference in user rates reflects the potential usage that could occur on the Lower Yarra trail.

Contactsl Source:

Cathy Buckley Lewis, Central Transportation Planning Staff, 10 Park Plaza, Suite 2150, Boston, MA 02116.

Marcus Wigan: Oxford Systematics, GPO Box 126, Heidelberg, Victoria, Australia 3084.

Publications:

Hoekwater, J. *Bicycle* Routes *in* the Hague and *Tilburg*. Published in Bicycling as a Mode of Transport: Proceedings of a Symposium held at the Transport and Road Research Laboratory, Crowthorne, U.K. (TRRL Supplementary Report 540), October 1978.

Lewis, Cathy Buckley and James E. Kirk, *Central Massachusetts Rail Trail Feasibility Study*, Central Transportation Planning Staff, Boston, MA, April 1997.

Wigan, Marcus, Anthony J. Richardson and Paris Brunton. *Simplified Estimation of Demand for* Non-motorized *Trails* Using GIS, Transportation Research Board, Preprint #981203, 1998.

Evaluative Criteria: How Does It Work?

Performance:

Examples where these methods had been validated in practice were not identified.

Use of Existing Resources:

Lewis/Kirk: These methods are simplified approaches that capitalize on the use of existing, albeit somewhat limited, resources.

Wigan/Richardson/Brunton: Since it is difficult to quantify the benefit of signage and linkage improvements as well as the impact of promotions on the usage of an existing facility, this method attempts to calculate the benefits using a comparable facility that has more sophisticated signage, linkages, and promotional opportunities.

Travel Demand Model Integration:

Not applicable.

Applicability to Diverse Conditions:

The methods use survey results that vary depending on the situation.

Usage in Decision-Making:

The methods provide a rough estimate concerning the demand that is likely to occur on proposed facilities.

Ability to Incorporate Changes:

The methods are able to incorporate changes into the analysis since the data inputs and computations are not complex.

Ease-of-Use:

Lewis/Kirk: The method is easy to use because it uses simple and widely available data.

Wigan/Richardson/Brunton: This approach is somewhat more complex than Lewis/Kirk, requiring the use of GIS and local travel surveys for analysis.

Demand Estimation:

2.2 Aggregate Behavior Studies

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☐ Pedestrian ☐ Facility-Level ☒ Area-Level

Authors and Development Dates:

Ashley and Banister (1989); Epperson, Hendricks, and York (1995); Ridgway (1995); Nelson and Allen (1997).

Purpose:

Aggregate behavior studies or models attempt to predict mode split and/or other travel behavior characteristics for an aggregate population, such as residents of a census tract or metropolitan area. Prediction is based on characteristics of the population and of the area. An example of an aggregate model would be a regression equation to predict the bicycle mode splits of individual census tracts in a metropolitan area, based on the average income of the tract and on the total length of bikeways in the tract. Aggregate behavior models can be contrasted with disaggregate models, which predict an individual's behavior and then aggregate individual decisions across a population to obtain overall travel characteristics.

Aggregate models can be used for the following purposes:

1. Identifying which factors influence overall levels of bicycling or walking in an area.

2. Predicting the change in levels of bicycling or walking caused by a change in one of these factors.

3. Predicting the amount of bicycling or walking in other areas, based on data collected in one area.

4. Developing data for use in a travel demand model.

Structure:

Linear regression equations are commonly used to predict an independent variable (bicycle mode split, number of trips, etc.) as a function of various dependent variables.

Calibration/Validation Approach:

A model can be developed based on one dataset and then applied to another dataset to check its validity. Attempts to do this, however, have yielded less-than-satisfactory results (c.f. Ashley and Banister, 1989; Ridgway, 1995).

Inputs/Data Needs:

All data must be obtained at the level of the unit of analysis (census tract, employment center, metropolitan area, etc.) A wide variety of data can be used in developing aggregate behavior models. Both the data used and the unit of analysis are generally constrained by what data can be obtained from available sources or collected with little additional effort.

Ashley and *Banister* obtained data at the ward level in the United Kingdom on characteristics of the population, trip distances, availability of other modes, traffic levels, and local climate/topographical factors. Some data were obtained from census records while other data required additional collection and analysis efforts. They also identified a number of variables that were desirable to have but could not be collected because of resource limitations.

Potential Data Sources:

Census Data: Population characteristics (socioeconomic and demographic), journey-to-work mode, density

Land use data bases

Topographic maps: topography

Roadway network data bases: traffic volumes, road characteristics

Computational Requirements:

Analysis can be conducted with spreadsheets or standard statistical software packages.

User Skill/Knowledge:

An ability to construct statistical models such as linear regression is required.

Assumptions:

It is assumed that travel behavior at an aggregate level can be predicted with relative accuracy given the data available. The implications of this assumption are discussed under "Comments."

Facility Design Factors:

Ashley and Banister considered terrain (hilliness) and traffic levels. Availability of bicycling facilities and terminal facilities were not included because of lack of data.

Inclusion of facility design factors in aggregate demand models would require measures of facility availability/quality which can be constructed at the area level. These might include miles of bike path or lane, miles of sidewalk, percent of road network in good cyclable condition, etc. Further development of road/facility network data bases using GIS techniques should allow easier incorporation of facility design factors. Pedestrian environment factors, such as those developed in Portland, OR, are an example of area-level facility design variables.

Nelson and Allen included per capita miles of bikeway in an analysis of work-trip bicycle use at the metropolitan area level.

Output Types:

Output is mode split or total trips by mode for an area as a function of variables describing the area.

Real-World Examples:

Ashley and Banister (1989) used UK census data to (1) evaluate factors influencing bicycling to work; (2) develop a model to predict the proportion of residents bicycling to work; and (3) test the model. A variety of factors were tested including personal characteristics, trip distance, availability of bicycling facilities, availability of other modes, traffic levels, and local climate/topographical factors.

Epperson, Hendricks, and York (1995) analyzed NPTS data to develop nationwide bicycle trip generation rates for 12 categories of people (stratified by age, gender, and race). These trip rates were applied to census tracts based on the number of people in each category by tract.

Nelson and Allen (1997) conducted a cross-sectional analysis of 18 U.S. cities to predict work trip bicycle mode split (from census data) based on weather, terrain, number of college students, and per capita miles of bikeway facilities. A positive association was found between the presence of bikeway facilities and bicycle work trip mode split.

Ridgway (1995) developed a regression model to estimate bicycle mode split at the city and census tract levels based on available data. Candidate variables were screened based on correlation with bicycle mode split. Those selected included age (percent of population under 25 years), and mean population travel time (a proxy for travel distance), and percent of student population.

Contacts/Source:

Chris Banister: Department of Planning and Landscape, University of Manchester, UK.

Bruce Epperson: Miami Metropolitan Planning Organization, Hollywood, FL.

Matthew Ridgway: Fehr and Peers Associates, Lafayette, CA.

Publications:

Ashley, Carol A. and Chris Banister. Bicycling *to Work from Wards* in *a Metropolitan Area.* Traffic Engineering and Control, Vol. 30, nos. 6-8, June – September 1989.

Epperson, Bruce, Sara J. Hendricks, and Mitchell York. *Estimation of Bicycle Transportation Demand from* Limited *Data.* (University of South Florida). Compendium of Technical Papers from the Institute of Transportation Engineers 65th Annual Meeting, pp. 436-440, 1995.

Nelson, Arthur C. and David Allen. *If You Build Them, Commuters Will Use Them: Cross-Sectional Analysis of Commuters and Bicycle Facilities.* City Planning Program, Georgia Institute of Technology, submitted to the Transportation Research Board, 76th Annual Meeting, Washington, DC (preprint), January 1997.

Ridgway, Matthew D. *Projecting Bicycle Demand:* An *Application of* Travel *Demand Modeling Techniques to Bicycles.* 1995 Compendium of Technical Papers, Institute of Transportation Engineers 65th Annual Meeting, pp. 755-785, 1995.

Evaluative Criteria: How Does It Work?

Performance:

Aggregate demand models to predict bicycling and walking mode shares tend to have low-explanatory power; that is, most of the factors which influence mode shares have not been accounted for in the model.

Ashley and Banister found that "while it is possible to isolate some factors in the form of a model for particular areas, when the model is applied elsewhere the fit is not so good." Also there are significant difficulties involved with developing a transferable model.

Ridgway found that while his model based on census data adequately predicted bicycle mode split using data from 18 California cities, it did not perform so well at predicting mode split for census tracts in Berkeley.

Use of Existing Resources:

Aggregate models can be constructed largely using existing data on population and land use characteristics. Aggregate-level data on network characteristics may require additional data collection and analysis, although further development of road/facility network data bases using GIS techniques should allow easier incorporation of facility design factor.

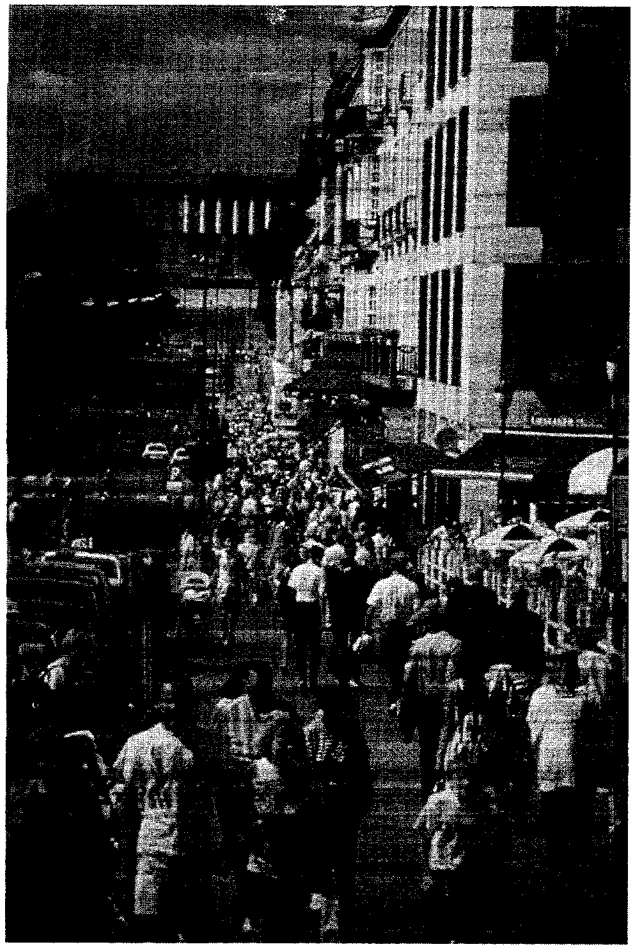

Figure 2.2 Aggregate models can be constructed largely using existing data on population and land use characteristics.

Travel Demand Model Integration:

Aggregate models are frequently used in the travel modeling process to predict total number of trips by trip purpose at the zonal level. The models discussed here differ primarily in that they attempt to predict only total bike or walk trips, rather than total trips by all modes. In travel demand models, mode choice is usually predicted separately at a later stage of the travel modeling process.

Applicability to Diverse Conditions:

Aggregate models have not yet been developed which have been demonstrated to be transferable to other situations or areas.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

Models can be re-estimated with relative ease if new data become available.

Ease-of-Use:

An ability to construct statistical models such as linear regression is required.

Comments:

It is assumed that travel behavior at an aggregate level can be predicted with relative accuracy given the data available. Some of the drawbacks of this assumption include:

- The method relies on aggregate-level data (i.e., averages/statistics for a population) rather than predicting the behavior of individual trip makers. Aggregate-level data can mask significant variances within a population which affect behavior (the problems with aggregation have been widely discussed in the literature on travel demand modeling).

- The method ignores the impact of factors which are not readily available, such as attitudinal factors.

- The primary data source on trips at a zonal/aggregate level is the census, which looks only at work trips.

- The available data generally do not include environmental variables such as the overall quality of the area for bicycling or walking, the overall quality of alternative modes, etc. Some pedestrian environment factors have been developed for this purpose, but only one known bicycle environment factor exists and its validity has not yet been proven. Also, these factors require significant local data collection. In most cases, density (population and/or employment) may be the only readily available proxy for environmental factors that describe the relative attractiveness of an area for bicycling or walking.

Demand Estimation:

2.3 Bicycle Sketch Plan Methods

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☐ Pedestrian ☒ Facility-Level •I Area-Level

Authors and Development Dates:

Goldsmith (1997)

Purpose:

Sketch plan methods can be defined as a series of "back-of-the-envelope" calculations to estimate the number of bicyclists using a facility or area. These methods generally rely on data that already exist or can be collected with relative ease (such as census and land use data), combined with behavioral assumptions derived from other studies. Sketch plan methods tend to vary widely in their specific approaches and in their level of sophistication.

Goldsmith (1997) developed and applied a sketch-plan method to estimate the impact of a new bicycle facility in the Seattle, WA, area on reducing motor vehicle VMT (vehicle miles of travel) and emissions.

Structure:

Goldsmith:

1. Determine the location and boundaries of the travel shed (i.e., the area from which most trips on the facility are expected to originate).

2. Determine the population of census tracts within the travel shed.

3. Use census or survey data to determine the percentage of daily commuters within the travel shed.

4. Use census or survey data to determine the bicycle mode split for each census tract within the travel shed.

5. Estimate the number of potential bicycle commuters using the rate of current bicycle commuting in the travel shed as a comparison. For example, if the travel shed has a higher bicycle mode split than the census, then the potential bicycle commuter rate also should be higher. Also could use the proportion of population under 45 years

relative to the city average to estimate the potential riding population. Multiply the rate by the total number of commuters in the travel shed and then subtract the number of current bicycle commuters.

6. Determine the expected number of new bicycle trips by assuming that a certain percentage of the population will divert trips from other modes to bicycling. For example, the Seattle survey showed that 26 percent of the potential bicycle commuting population would become bicycle commuters.

7. Determine the proportion of these trips that came from single-occupancy vehicle (SOV) trips. For example, the Seattle survey showed that one in two would be diverted from SOV trips.

8. Determine trip lengths using the city-wide average or one calculated from central locations within the census tracts to main trip generators.

9. Calculate the estimated number of VMT eliminated and emissions prevented using emissions assumptions as shown below in the "Assumptions" entry.

Calibration/Validation Approach:

Goldsmith: The technique should be tested in other settings to ensure its transferability. Furthermore, before and after bicycle counts could help to better improve the accuracy of this type of estimation technique.

Inputs/Data Needs:

Goldsmith: The VMT/emissions model requires the following data items:

- Geographic area that is affected by a bicycle facility, which also is known as the "travel shed";
- Population and journey-to-work census data for the travel shed;
- Current bicycle patterns within the travel shed, especially origin and destination information as well as key bicycle routes; and
- Emission factors per trip and VMT for the purpose of calculating emission reductions.

Potential Data Sources:

Goldsmith: Not applicable.

Computational Requirements:

Goldsmith: Uses spreadsheets.

User Skill/Knowledge:

Goldsmith: Users should be familiar with the bicycle-related data that are available in the respective area.

Assumptions:

Goldsmith: The following assumptions were made for each information need:

- Travel shed identification. A 0.8-km buffer is the standard approach used to create a corridor-specific travel shed. Other criteria also should be considered, such as the proximity of alternative bicycle routes and physical barriers like mountains or highways. For example, the proposed Pine Street facility has a larger travel shed to the north because very few bicycle facilities are located in this area whereas the travel shed in the south is small since an alternative facility is in close proximity.

- The proportion of new bicycle trips. To estimate commuter bicycle trips, first multiply the percentage of residents who commute on a daily basis (60 percent in Seattle) by the population of the travel shed. With the commuting population number, multiply it by the bicycle commute rate. This calculation gives existing estimated bicycle commute trips. An estimate for potential bicycle commuters is determined through survey data that reveals that percentage of residents who at one point bicycle commuted. Subtract this percentage from the current bicycle commute rate to obtain the percent of potential new bicycle commuters (Seattle used 8 percent). This number is then multiplied by the number of commuters in the travel shed and then by the number of commuters who said that they would switch to bicycling if safer facilities were provided (26 percent in Seattle). The equation is as follows:

  # new bicycle commuters = # CBD (central business district) commuters * percent potential bicycle commuters * percent ride on safe facilities

- Non-work trip estimates: Since data are scarce concerning utilitarian non-work trips, the method relies on national surveys that show these trips as 50 to 100 percent more frequent than work trips. In Seattle, household travel survey data show that there are about 70 percent more utilitarian non-work trips than work trips.

- The proportion of these trips that would have been motorized vehicular trips (as opposed to transit diversions). The estimate for the substitution rate is based on the area's rate of single-occupancy vehicle (SOV) travel. Seattle's proportion of SOV commutes is 60 percent, so Seattle conservatively chose a 50 percent substitution rate meaning that one out of every two bicycle commute trips replaces an SOV trip. For utilitarian non-work trips, only one of three trips were assumed to be diverted from SOV travel, since these trips tend to be much shorter and could be accomplished by non-automobile modes.

- The average length of these SOV diverted trips. Commuting distances are estimated using census journey-to-work data. Minutes were converted into miles using an assumption that the average bicyclist travels at about 16 km/h or 1.6 km every 6 minutes. The average commute length is between 3.93 and 5.22 km based on low and high estimates. For utilitarian non-work trip distances, the commuting distance was divided in half. For

Seattle, the average one-way non-work bicycle trip distance was estimated at 1.43 km, or one-half the average of 3.93 and 5.22.

Facility Design Factors:

Goldsmith: This method does not consider the impact of facility design factors on bicycle travel demand.

Output Types:

Goldsmith: The output consists of new bicycle commute and non-work utilitarian trips per day, and their impact on reducing SOV trips, VMT, and emissions. The following table illustrates the estimated reductions in SOV trips and VMT.

	New Commute and Utilitarian Bicycle Trips Due to Pine Street, Seattle Bicycle Lanes: Projected Totals			
	Average Round Trip Length	**Projected New Bicycle Trips**	**SOV Trips Eliminated**	**VMT Avoided**
Daily Commute Trips = (a)	3.56	**144**	72	244
Daily Non-work Trips = (b)	1.78	**381**	127	217
Total Daily Reductions = (a) + (b)		525	**199**	461
Total Annual Reductions = 250 * (a) + 365 * (b)		175,065	64,355	**140,205**

Real-World Examples:

Goldsmith: Proposed bicycle lanes on Pine Street in Seattle, Washington, were used as the case study for the method. Examples taken from this case study are shown above in the input, output, and assumptions entries. The author would like to test this method on other proposed facilities to ensure its transferability.

Contacts/Source:

Stuart Goldsmith, City of Seattle, Engineering Department, Seattle, WA.

Publications:

Goldsmith, *Stuart, Draft: Estimating the Effect of Bicycle Facilities on VMT and Emissions,* Seattle Engineering Department, 1997.

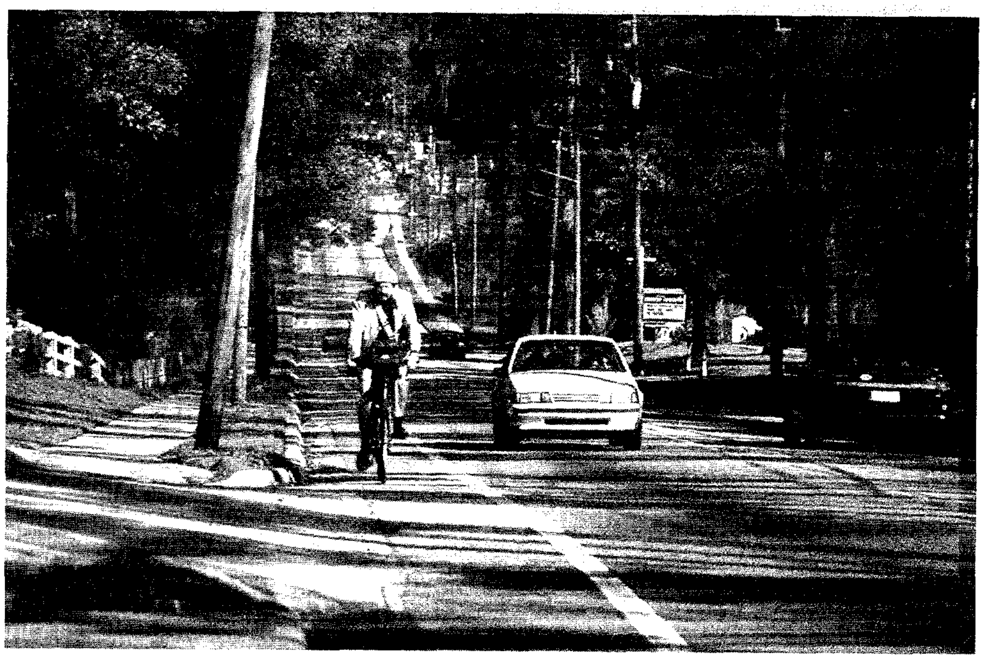

Figure 2.3 A bicycle facility is likely to divert some trips from other modes to bicycling.

Evaluative Criteria: How Does It Work?

Performance:

Goldsmith: The author believes that the method provides reasonable estimates of the impact that a new facility would have based on limited data such as census and travel survey data. The performance of the model in other situations has not been tested; local conditions vary considerably and bicycle-related data may be scarce in most jurisdictions. Furthermore, a number of assumptions are made in estimating the travel shed, current number of bicycle trips, and percentage of people who would choose to bicycle as a result of the new facility.

Use of Existing Resources:

Goldsmith: The method uses readily available data such as the census and local household travel survey data. The method also can use local preference surveys regarding travel behavior, although such survey data do not always exist.

Travel Demand Model Integration:

Goldsmith: The method is not designed for integration with regional travel models.

Applicability to Diverse Conditions:

Goldsmith: The inputs vary depending on the locality. For example, the travel shed is determined on a case-by-case basis. Once the travel shed is selected, the demographics and bicycle trip information then can be assessed.

Usage in Decision-Making:

Goldsmith: The method could be used to determine the VMT and emission reductions that could occur from specific proposed bicycle-related projects. This information is needed for air quality-related funding sources such as the Congestion Mitigation and Air Quality (CMAQ) program.

Ability to Incorporate Changes:

Goldsmith: Changes to the inputs can be easily incorporated into the estimation technique.

Ease-of-Use:

Goldsmith: The technique uses transportation data such as census data, and other existing data from transportation surveys.

Demand Estimation:

2.4 Pedestrian Sketch Plan Methods

Descriptive Criteria: What is It?

Categories:

☐ Bicycle ☐ Pedestrian ☐ Facility-Level ☐ Area-Level

Authors and Development Dates:

Pushkarev and Zupan (1971); Behnam and Pate1 (1977); Davis, King, and Robertson (1991); Matlick (1996); Ercolano, Olson, and Spring (1497)

Purpose:

A variety of pedestrian sketch-plan methods have been developed to estimate pedestrian volumes under existing and future conditions in a pedestrian activity area. These methods generally use pedestrian counts and regression analysis to predict pedestrian volumes as a function of adjacent land uses (e.g., square feet of office or retail space) and/or indicators of transportation trip generation (parking capacity, transit volumes, traffic movements, etc.). Alternatively, data on surrounding population and employment may be combined with assumed tip generation and mode split rates to estimate levels of pedestrian traffic.

These methods can be used to identify areas of high-pedestrian traffic based on existing land use data, thereby eliminating the need to conduct pedestrian counts on all facilities. They can also be used to forecast changes in pedestrian volumes as a result of future land use or transportation trip generation changes.

Pushkarev and Zupan (1971) and *Behnam and Patel* (1977) forecast pedestrian volumes in high-density urban areas based on existing land use characteristics and pedestrian volumes for specific locations. Similar studies were performed in other areas in the 1960s and 1970s for the purposes of developing pedestrian demand models (see entry for "Pedestrian Demand Models," Method 2.11)

Ercolano, Olson, and Spring (1997) use existing data routinely collected by most transportation providers (at a minimum, vehicles per hour from traffic counts and local mode shares from the census) to estimate peak pedestrian travel demand in suburban and developing rural activity centers. This sketch-planning method has been applied to help determine the location of pedestrian facility improvements such as pedestrian crossings, sidewalks, and signal retimings.

Matlick (1996) used household population, national transportation survey percentages, and activity center data to calculate potential walking trips in specific corridors. It is a quick method or tool to be used by planners to identify the priority areas for pedestrian facility expenditures.

Davis, King, and Robertson (1991) describe a method to measure and predict pedestrian crosswalk volumes for the evaluation of traffic signal requests and for the compilation of hazard indices. This method of only using short-term counts of 5 to 10 minutes is more cost effective than continuous counts. While this technique does not actually forecast demand, the issues discussed are relevant to the collection of pedestrian data for the other methods described here.

Structure:

Pushkarev/Zupan: Pedestrian volumes were determined on midtown Manhattan surface streets at various times of day using aerial photography. Regression analysis was then used to predict total pedestrian volumes per block. Independent variables included adjacent land uses (square feet of office, retail, and restaurant), distance to transit entrances, and sidewalk and plaza space per block. (A Manhattan-specific factor, whether the walkway was on a street or avenue, was also included.) Flow characteristics by time of day, traffic characteristics, and trip generation characteristics of specific types of buildings were also analyzed.

Behnam/Patel: Similar to Pushkarev/Zupan, regression models were used to estimate the noon-hour and average pedestrian volumes per hour, based on land use data. Behnam/Patel included eight types of land uses as the independent variables (see "Inputs/Data Needs.") Pedestrian volume per hour per block is the dependent variable of the regression. Mid-block sidewalk counts were used to determine pedestrian volumes for estimating the model. Future volumes were then predicted based on forecasts of future land use. Behnam/Patel applied this technique to the Milwaukee central business district.

Ercolano/Olson/Spring: Pedestrian per hour (PPH) values are derived from peak vehicles per hour (VPH) data, transit vehicle/ridership, and non-motorized mode-share estimates. A real-world application is described for a shopping area in Plattsburgh, NY. The steps taken are as follows:

1. Estimate the sources of the pedestrian trips (car/walk-linked trips, walk/bike-only trips, and transit/walk-linked trips). Regarding the trips originating from vehicles, all through traffic including limited-access highway ramp traffic should be eliminated from the analysis (approximately 70 percent of the peak traffic was eliminated in the NY case). A portion of the remaining VPH trips (i.e., turn movements) also should be eliminated because they are assumed to be drive through, truck or drop off/pick up trips (about 20 percent of the trips were eliminated in the NY model case study). For urban areas with fewer than 50,000 residents in the region, walk/bike only and transit trips were considered as part of the remaining peak VPH turning movements.

2. Estimate the average peak pedestrian per hour (PPH) trip rates per person. This is done by combining the vehicle-tip estimates from step 1 with an assumed average vehicle occupancy rate and number of walk trips per hour (assumed to be 1.5 persons/vehicle and five walk trips per person per hour in the Plattsburgh, NY example).

Steps 1 and 2 can be summarized as follows:

Peak PPH = (Peak VPH – Through Movement Trips) =
(VPH Turning Movements x 1.5 Default Average Vehicle Occupancy x 5 Trips Per Person – 20 percent Drive-Through).

3. Distribute and assign PPH trips. Pedestrian trips are categorized into three groups: internal, external, and extended. Internal trips occur within a traffic analysis zone (TAZ); external trips may begin or end in a different zone; and extended trips are longer trips through several zones. To avoid double counting, extended walk-trips need to be weighted per zone using projected peak-hour VPH turning volumes. The adjusted PPH is used to calculate walk trip volumes by season.

Once the PPH trip estimates are assigned and distributed, it is possible to recommend proposed intersection and midblock improvements. When the average hourly pedestrian and vehicle volumes reach a certain level, it is recommended to install crosswalks, pedestrian signals, or refuge islands/medians. For example, the minimum for a crosswalk installation is 200-300 VPH and 25 PPH. When children, elderly or disabled pedestrians are the majority, the minimum is reduced to 100 VPH and 10 PPH.

Matlick: The method uses household population and national transportation survey percentages to calculate potential walking trips. The steps for a corridor-level analysis are as follows:

1. To represent the majority of pedestrian trips, identify a 0.8-km buffer around the selected corridor. GIS possess tools that enable planners to create buffers.

2. Identify traffic generators such as the number of housing units by dwelling type, average persons per unit for each dwelling type, and the average number of trips per person from these locations.

   Total Corridor Generated Trips (TCGT) = Population x Trips Per Person

   Potential Pedestrian Trips (PPT) = TCGT x (Total All Trips < 0.8 km)

   Est. Primary Pedestrian Trips = PPT x (Percent Known Walking Trips < 0.8 km)

   OR

   Population x Pedestrian Mode Split for the area (if available)

3. Identify traffic attractors such as retail, recreational, social facilities, schools, transit stations, and churches. Since most pedestrian tips are less than 0.4 km, it is important that traffic generators and attractors are in close proximity. Areas with high levels of attractors are likely to have a higher potential for pedestrian activity. When associated with nearby traffic generators, optimal conditions for pedestrians exist.

4. Locate transit, school, and park and ride data to validate the estimated pedestrian trip numbers (refer to "Calibration/Validation Approach" for more details).

Davis/King/Robertson: The technique only requires short-term vehicle counts of 5-, 10-, 15- or 30 minutes over a 1- to 4hour period. Pedestrian counts that are recorded in the middle of the hour are shown to have greater accuracy as opposed to counts at the beginning or end of an hour. Furthermore, short-term counts taken over 4 hours are more accurate than counts taken over 1 to 3 hours. The method gives detailed instructions for designing a data collection experiment, including (1) selecting the type of application; (2) selecting the count interval; (3) collecting the data; and (4) computing estimated volumes.

Calibration/Validation Approach:

Pushkarev/Zupan and *Behnam/Patel:* Sidewalk pedestrian counts in the areas analyzed (Manhattan and Milwaukee CBD) were used to develop the quantitative models. If applied to other cities or areas, the models could be reestimated based on pedestrian counts from the specific area.

Ercolano/Olson/Spring: The results of the case study were cross-referenced with a land-use-based study for the same area done in 1978 by Kagan, Scott, and Avin. Kagan et al. used counts from 215 city sites to develop trip-rate averages by land use type. Predicted volumes were in relatively close agreement, with values from Ercolano, et al.'s access-egress method being 7, 24, and 29 percent lower in the three applicable zones than based on the earlier land use-based method.

Matlick: To ensure the accuracy of the estimated primary pedestrian trips calculated in step 2, compare this number to transit ridership and the number of non-bussed schoolchildren. The number should be about the same as the number obtained in step 2.

Davis/King/Robertson: Four out of the 12 sites were used to validate the expansion model. These sites were located in the same city yet their volume distribution patterns differed. The percent difference between the actual and predicted counts ranges between 11.9 percent and 34.5 percent.

Inputs/Data Needs:

Pushkarev/Zupan: For each city block, required data include:

- Square m of office, retail, and restaurant space;
- Square m of sidewalk and plaza space; and
- Distance to nearest transit station.

Behnam/Patel: Requirements include pedestrian volumes at the four corners of a block and the following land use data:

- Commercial space;
- Office space;
- Cultural and entertainment space;
- Manufacturing space;
- Residential space;

- Parking space;
- Vacant space; and
- Storage and maintenance space.

Ercolano/Olson/Spring: The method uses walk-trip counts; if this information is not available, the following data sources could be used:

- Peak vehicle-per-hour (VPH) turning movements;
- Transit ridership;
- Walk/bike only mode shares (based on the U.S. Census);
- Zoning or land use map;
- Square meters or feet of new development space; and
- Aerial photographs and/or specific site, corridor, or subarea block configurations.

Matlick: Desired data include:

- Land uses;
- Maps;
- Transportation mode split information;
- Generator information: Housing types, density, persons per household unit, and hotels;
- Attractor information: retail, recreation, social facilities, schools, employment, and churches;
- Daily transit ridership information;
- Local school information: number of enrolled children, percentage of bussed and non-bussed students; and
- Park and ride lot information: lots, size, and occupancy rates.

Davis/King/Robertson: The method requires pedestrian counts over a 1- to 4-hour period for 5-, 10-, 15-, or 30-minute time segments. For traffic signal requests, the analysis requires data from the peak hour. The count data can be collected manually, as suggested by the author, or using new advanced traffic sensors as they become more commonplace.

Potential Data Sources:

Pushkarev/Zupan and *Behnam/Patel:* Local land use data bases.

Ercolano/Olson/Spring: Vehicle traffic counts, zoning/land use maps, other site or area maps.

Matlick: Traffic Analysis Zones (TAZ), U.S. Census block tracts, regional socioeconomic, and transportation data.

Davis/King/Robertson: Not applicable.

Computational Requirements:

Pushkarev/Zupan and *Behnam/Patel:* Regression analysis is required.

Ercolano/Olson/Spring and *Matlick:* The computations can be done using spreadsheets.

Davis/King/Robertson: The methods uses simple equations.

User Skill/Knowledge:

Pushkarev/Zupan and *Behnam/Patel:* The user should be familiar with localized land use and transportation data and with techniques of regression analysis and traffic counting methods.

Matlick: The user should be familiar with localized land use, socioeconomic, and transportation data.

Ercolano/Olson/Spring: The user should have some knowledge of general modeling assumptions and methods as well as knowledge of the specific site, corridor, or subarea.

Davis/King/Robertson: The user should be familiar with survey and traffic counting methods.

Assumptions:

Pushkarev/Zupan and *Behnam/Patel:* It is assumed that the land use variables included can adequately predict pedestrian volumes. Other factors that may affect pedestrian trip generation rates, such as pedestrian environment quality, are not analyzed.

Ercolano/Olson/Spring: For urban areas with fewer than 50,000 residents in the region, walk/bike only and transit trips are assumed to be part of peak-vehicle turn movements that are used in the study. For urban areas with regional populations that exceed 50,000, the analyses would have to be separate for pedestrian trips by car, walking/biking only, and transit modes.

Matlick: Using the Nationwide Personal Transportation *Survey* (NPTS), *the* method utilizes national travel data when regional- or corridor-level data does not exist.

Facility Design Factors:

Pushkarev/Zupan: Considers sidewalk width and/or total sidewalk and plaza area.

Behnam/Patel: The method does not consider the impact of facility design factors.

Ercolano/Olson/Spring: The method accounts for the following different levels of pedestrian facility designs: nonexistent, partial, and complete.

Matlick: The method does not consider the quality of pedestrian facilities.

Davis/King/Robertson: The method considers only existing pedestrian volumes.

Output Types:

Pushkarev/Zupan and *Behnam/Patel:* Existing pedestrian volumes can be predicted based on land uses if pedestrian counts are not available, and future pedestrian volumes can be predicted as a function of future land uses.

Ercolano/Olson/Spring: The estimated intersection crossing data are categorized according to zone, level of pedestrian facility completeness, and season/climatic condition.

Matlick: The output consists of two estimates, one for traffic generators and the other for attractors. The generator estimate states the number of primary potential pedestrian trips in the corridor while the attractor estimate reveals the number of customers, employees and students in a given area. Planners can use this data when comparing corridors for future pedestrian facility improvement projects.

Davis/King/Robertson: The output of this method is an expanded pedestrian volume for a period from 1 to 4 hours, depending on the number of hours used in the counting procedure.

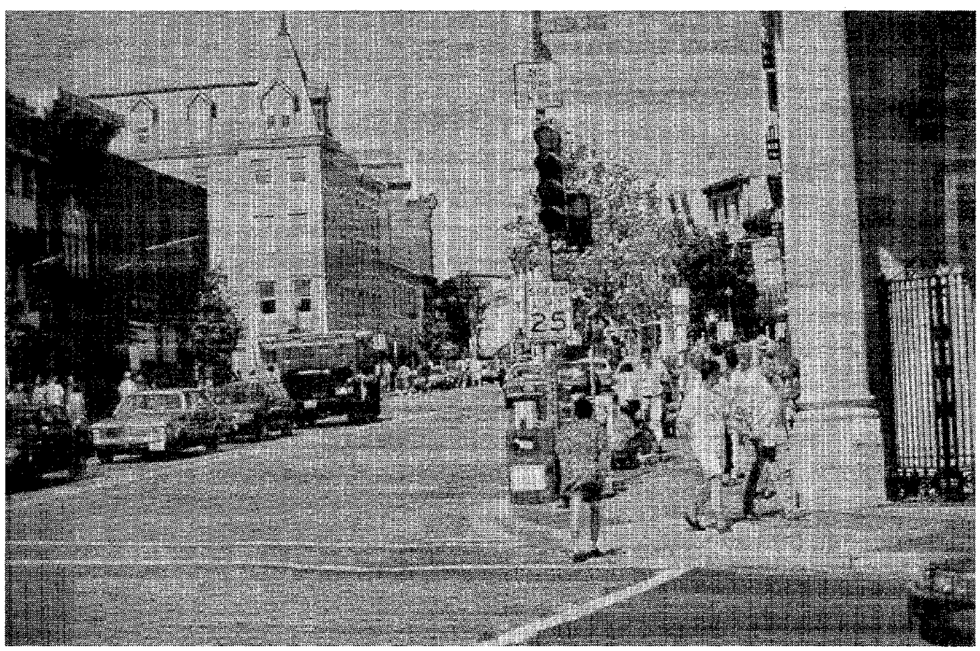

Figure 2.4 Data on surrounding population and employment may be combined with assumed trip generation and mode split rates to estimate levels of pedestrian traffic.

Real- World Examples:

Pushkarev/Zupan: Models of pedestrian traffic were developed for midtown Manhattan.

Behnam/Patel: The case study for the report was the CBD of Milwaukee.

Ercolano/Olson/Spring: The case study was a suburban growth corridor in Plattsburgh, New York. Some of the specific findings are shown in the above "Structure" section.

Matlick: The case study was a suburban roadway corridor in Seattle, Washington. Results are described under "Performance."

Davis/King/Robertson: The case study was developed from data collected in Washington, DC, which involved over 18,000 5-minute pedestrian count intervals.

Contacts/Source:

Scott Davis: Analysis Group, Inc., 500 E. Morehead Street, Suite 315, Charlotte, NC, 28202.

L. Ellis King and H. Douglas Robertson: Civil Engineering Department, University of North Carolina at Charlotte, Charlotte, NC, 28223.

James Ercolano, Jeffrey Olson, and Douglas Spring: New York State Department of Transportation (Albany, NY)

Jeff Zupan, Regional Plan Association of New York (New York, NY)

Publications:

Behnam, Jahanbakhsh and Bharat G. Patel, *A Method for Estimating Pedestrian Volume in a Central Business District,* Pedestrian Controls, Bicycle Facilities, Driver Research, and System Safety, Transportation Research Record 629, Washington, DC, 1977.

Davis, Scott E., L. Ellis King and H. Douglas Robertson, *Predicting Pedestrian Crosswalk Volumes,* Transportation Research Record 1168, Washington, DC, 1991.

Ercolano, James M., Jeffrey S. Olson, Douglas M. Spring, *Sketch-Plan Method for Estimating Pedestrian Traffic for Central Business Districts and Suburban Growth Corridors,* Transportation Research Record 1578, Washington, DC, 1997.

Matlick, Julie Mercer. *If* We *Build it, Will They* Come? #69 Forecasting Pedestrian Use and Flows, Forecasting the Future, Bicycle Federation of America — Pedestrian Federation of America, Pro Bike/Pro Walk '96, 1996, pp. 315-319.

Pushkarev, Boris and Jeffrey M. Zupan. *Pedestrian Travel Demand.* Highway Research Record 355, 1971.

Evaluative Criteria: How Does It Work?

Performance:

Pushkarev/Zupan: Similar comments apply as for Behnam/Patel, but the analysis is specific to Midtown Manhattan, and more expensive aerial photography data collection techniques are used.

Behnam/Patel: The method works well for high-density urban areas but has not been applied to low-density areas. The data collection process is not labor intensive and requires only standard information making the method cost-effective. The process takes into consideration the geographical distribution of pedestrians yet is best used at the central business district or facility level, not at a city level.

Ercolano/Olson/Spring: Pedestrian volumes predicted from this sketch planning method compared reasonably well with those predicted based on the trip generation of adjacent land uses. *Moudon* (see TRR 1578) also provided evidence that "completeness of pedestrian facilities, etc." supports more pedestrian travel and influences mode share.

Ma tlick: The traffic generator estimate equals 1,378 primary pedestrian trips in the corridor; the validation for the traffic generator estimate is reasonable at 1,133. The attractor information consists of 500 students who attend class on a daily basis at the local college (branch) campus, 1,200 weekday customers at the grocery store, and 3,169 daily transactions at one of the fast food establishments.

Davis/King/Robertson: The method works well for the city in which the study was conducted. Further research needs to be done on its accuracy in other cities. Additional research also would improve the multi-hour estimates since a lower confidence was used for these hourly counts. The expansion model provides an easy and cost-effective method to estimate pedestrian volumes over a 1- to 4hour period.

Use of Existing Resources:

Pushkarev/Zupan and *Behnam/Patel:* The method uses land use data that can be obtained from the planning departments of any major city. Pedestrian counts also are required.

Ercolano/Olson/Spring: The method uses vehicle data that is routinely collected at the local level. The vehicle data can be substituted for more specific pedestrian-traffic count data if available. The method also provides a basis for more refined modeling for pedestrian accommodations during the project design to implementation phases.

Matlick: The method uses basic population data along with national transportation trip survey percentages that can be substituted for more site-specific transportation data.

Davis/King/Robertson: Any pedestrian counts using 5-, 10-, 15-, or 30-minute intervals over a l-, 2-, 3-, or 4hour period could be used. Manual counts were used in this example yet more high-tech means also could be used such as infrared and videotaping systems when these technologies progress.

Travel Demand Model Integration:

Pushkarev/Zupan and *Behnam/Patel:* Their methods were meant to assist with facility-level planning not city-wide analysis. The trip generation relationships could be used as inputs to local pedestrian travel demand models, if such models were developed.

Davis/King/Robertson, Ercolano/Olson/Spring, and *Matlick:* Their methods were not designed for model integration.

Applicability to Diverse Conditions:

Pushkarev/Zupan and *Behnam/Patel:* The general technique is probably most applicable to high-density CBD areas. The specific models developed are probably applicable only to the city/area in which they were developed.

Ercolano/Olson/Spring: The authors believe that the method can be applied to other areas, and site-specific data can be substituted for default inputs. The method is able to adjust for seasonal variations and for different infrastructure scenarios. The different infrastructure scenarios range from complete (i.e., ADA-compliant sidewalks, medians/refuge islands or pedestrian-oriented crossings) to partial (i.e., limited facility amenities) to nonexistent.

Matlick: The method uses national transportation data although site-specific data can be substituted when available.

Davis/King/Robertson: The model is able to accommodate for different sampling procedures such as surveys for different time allotments (i.e., 5-, 10-, 15- and 30-minutes), and for different time periods (i.e., 1 to 4 hours).

Usage in Decision-Making:

Behnam/Patel and *Ercolano/Olson/Spring:* The methods were developed to help determine the location of pedestrian facility improvements such as pedestrian crossings, sidewalks, and signal retimings.

Matlick: The method was developed as a tool to help planners compare potential corridor-level pedestrian activity.

Davis/King/Robertson: The expansion model was developed to provide planners with a cost-effective method for measuring existing pedestrian volumes for the evaluation of traffic signal warrants and for the establishment of hazard indices.

Ability to Incorporate Changes:

Behnam/Patel: The inputs can be easily updated.

Ercolano/Olson/Spring and *Matlick:* The vehicle traffic counts and national transportation survey data that are used as the default can be substituted for actual field data.

Davis/King/Robertson: The counts can easily be taken again since the time increments only amount to between 5 and 30 minutes.

Ease-of-Use:

Behnam/Patel, Ercolano/Olson/Spring, and *Matlick:* The methods are easy to understand since they use basic transportation data as inputs and can be manipulated using spreadsheets.

Davis/King/Robertson: The method is easy to understand and inexpensive to implement.

Comments:

Ercolano/Olson/Spring: The primary purpose of this research was to develop a quick sketch plan method to ensure consideration of pedestrian access and safety during project scoping/initiation. Completeness of pedestrian facilities was also viewed as an important factor in supporting more pedestrian travel and influencing mode share, as evidenced in Moudon, et al. (1997).

Matlick: Matlick's study uses the 1990 NPTS data. The 1995 NPTS is now available and provides more detail on personal travel. The use of the data remains limited by the size of the sample for non-motorized trips (6.3 percent).

■ 2.5 Discrete Choice Models

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☒ Pedestrian ❑ Facility-Level ❑ Area-Level

Purpose:

A discrete choice model predicts a decision made by an individual (choice of mode, choice of route, etc.) as a function of any number of variables, including factors that describe a bicycle or pedestrian facility improvement or policy change. The model can be used to estimate the total number of people who change their behavior in response to an action. As a result, the change in both non-motorized and motorized trips and distance of travel can be estimated. The model can also be used to derive elasticities, i.e., the percent change in bicycle or pedestrian travel in response to a given change in any particular variable.

Structure:

For a general discussion of discrete choice modeling principles and methods, see Ben-Akiva and Lerman (1985) and Horowitz, Koppelman, and Lerman (1986). Key points are summarized here.

A discrete choice model is a mathematical function which predicts an individual's choice based on the utility or relative attractiveness of competing alternatives (for example, bike or drive). The logit function is a common mathematical form used in discrete choice modeling.*

The model generally includes characteristics of the individual (e.g., age, gender, and income) and relative attributes of competing choices (e.g., cost and time of auto vs. bike travel). It also might include environmental factors, personal attitudes, or other factors which are thought to influence the choice in question. The model is developed from a data set containing individual trip decisions, characteristics of alternative choices for the trip, geographical characteristics, and characteristics of the individual.

A simple discrete choice model, for example, might be used to predict the probability of taking a trip by bicycle vs. by car, based on three factors:

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[1] **The logit function is au 'S-shaped" function relating one or more independent variables, such as the difference in auto and bicycle travel times, to the probability of making a specific choice, such as choosing to bicycle.**

1. Time difference between the two modes for the trip.
2. Whether the respondent is male or female.
3. Whether or not bicycle lanes are available.

The estimated coefficients (or weights for each factor) can be used to derive elasticities. Elasticities indicate the percent change in the variable being predicted (i.e., probability of choosing a mode) for a given change in one of the independent variables, holding the other variables constant. While transferring elasticities to realworld situations involves a number of assumptions, the elasticities may be used to estimate the change in users as a function of a given change in a facility or policy variable.

Ideally, instead of simply using elasticities, the model is applied to the entire affected population to estimate the total number of people who will change their behavior as a result of an improvement. To do this, an affected population must be defined. Examples of such a population might be residents in a census tract or transit users who access a particular transit station. The population must be defined in groups for which either an average value or a distribution is known for every variable in the model.

There are three alternative methods for aggregating results for the population (Horowitz, Koppelman, and Lerman, 1986):

1. The "naive" method. Average values are assumed for each variable except the one of interest. In the current example, an average trip time difference and an average gender value (such as 50 percent M/ 50 percent F) are used, and the probability of choosing the bicycle mode is compared with and without bike lanes. Significant errors may be introduced, however, by using single aggregate values for population variables.

2. The "market segmentation" method. The population is divided into groups (i.e., male vs. female and with different travel distances). For each group, a mode choice probability is estimated, multiplied by the total population of the groups, and summed across all groups. This is repeated with and without bicycle lanes, and the total numbers of bicycle trips for the two alternatives are then compared. This reduces, but does not eliminate, aggregation errors. The method is widely used in practice (see Wilbur Smith Associates, 1996).

3. The "sample enumeration" method. This method takes a random sample of the total population, estimates a mode choice probability for each person in the sample, and averages the sample probabilities to estimate a mode share for the entire population. This method is the most accurate of the three but is also the most difficult to apply.

Calibration/Validation Approach:

Discrete choice models developed from stated-preference surveys can be calibrated/validated using models developed from data on actual (revealed) behavior (see "Inputs/Data Needs").

Inputs/Data Needs:

Discrete choice models are developed from data sets containing individual trip decisions, including characteristics of the individual and of alternative choices for the trip. Two types of data, revealed-preference and stated-preference, may be used, as described below:

1. "Revealed-preference" data, or data on actual behavior. This may be collected from a travel survey, which determines characteristics of a trip (origin and destination, mode, travel time, etc.) as well as characteristics of the individual and other influencing factors. Observations on trip decisions by 1,000 to 3,000 people are required. (Horowitz et al., 1985).

For this type of data to be useful for predicting non-motorized travel, the data set must include the following:

- Characteristics of the non-motorized mode alternative for each trip, such as time, cost, facility or environment factors of interest, etc., even if the trip was not taken by the non-motorized mode.

- Enough observations of people taking non-motorized trips that this choice can be reasonably estimated from the other variables in the model.

While travel survey data are routinely collected in many metropolitan areas, at least one of these criteria is usually not met. Therefore, use of revealed-preference data to predict non-motorized mode choice generally requires additional data collection efforts. Potential sources of both existing data and new data are discussed in the following sections.

An additional limitation to the use of revealed-preference data to forecast bicycle or pedestrian travel is that it cannot predict the impact of non-motorized improvements that do not yet exist. For example, if an extensive network of bicycle paths is to be developed but bicycle paths do not yet exist in the area, no observations are available to predict the use of these facilities. In cases of hypothetical improvements, a second type of data must be collected:

2. "Stated-preference" data. To collect this type of data, respondents are asked to identify the choices they would make under various scenarios. For example, different combinations of the relative trip time, cost, and presence of bike lanes would be presented, and for each combination, the respondent would choose whether to drive or bicycle.

This method is capable of evaluating a wide range of factors that may or may not yet exist. However, it has at least three significant drawbacks:

- First, respondents are frequently overly optimistic when responding to hypothetical questions (Hunt and Abraham, 1997). For example, asking people "if they would bicycle, given factor X" will significantly overestimate the actual number of people who will switch to bicycling if factor X is provided. This problem can largely be overcome through the design of survey questions that force people to make tradeoffs between attributes, and by relating their responses to similar tradeoffs to their actual behavior.

- Second, respondents must imagine what their choices would be like rather than experiencing them directly, and they may not accurately be able to judge their response to a situation that they have not encountered. This is a particular problem for evaluating bicycle and pedestrian facilities for which qualities of the physical environment (pavement smoothness, traffic noise, etc.) may be significant factors. Visual simulation techniques such as those used by Wilbur Smith Associates (1996) can partially although not completely overcome this drawback.

- Third, the range of factors to be evaluated must be kept simple and phrased in terms that people can conceptualize them. For example, people may be able to predict their choice to walk given the "presence or absence of a sidewalk," but not as a specific function of sidewalk design, street crossing types, and other factors that make up the pedestrian environment.

- Finally, respondents may say what they think the interviewer wants to hear rather than expressing their true opinion. This problem may vary depending on the methodology used to implement the survey and the ways in which the survey questions are phrased.

Stated-preference surveys are discussed further under the entry on "Preference Surveys."

Figure 2.5 In a stated-preference survey, respondents are asked to choose between alternatives with different attributes.

Potential Data Sources:

Mode choice models including bicycling and/or walking are usually developed directly from the results of special data collection efforts. The most common type is to conduct a stated-preference survey of users and potential users. Respondents are asked to choose between alternatives with different attributes. The results of these choices are then combined with information about the respondent, her/his current choice of the presently available alternatives, and other environmental factors, to develop a predictive model.

Household travel surveys are a potential existing source of revealed-preference data. These surveys are conducted routinely by many Metropolitan Planning Organizations (MPOs), although not all have included non-motorized travel in the past. Metropolitan travel surveys, however, generally suffer from two major limitations for developing discrete choice models of non-motorized travel:

1. Characteristics of non-motorized alternatives for each trip are generally not collected, so the effects of changing policies or improving facilities cannot be evaluated.

2. Most surveys do not include enough observations of non-motorized trips to develop predictive models for these modes.

It is possible that the first limitation could be overcome by collecting additional data describing existing bicycle/pedestrian facilities or environments, so that these factors can then be related to the locations of survey respondents and used as a predictor of travel decisions. However, the effort involved in collecting this data could be considerable.

The National Personal Travel Survey (NPTS) is another potential source of individual travel behavior data, although collection of local facility or environmental data for inclusion in a model based on this data source would again be difficult and the amount of geographic detail in the survey is limited.

Surveys of transit access mode are sometimes conducted by transit agencies and have also been used as a data source for predicting access mode choice (Wilbur Smith Associates, 1996; Loutzenheiser, 1997). An advantage of these surveys is that they contain a significant percentage of non-motorized trips and generally distinguish between walk and bicycle access. Transit access surveys may need to be supplemented with additional site-specific data collection on bicycle and/or pedestrian facility factors to evaluate the effects of these factors.

Models can also be developed from special revealed-preference data collection efforts, which relate information from counts and/or surveys of users to descriptors of the facilities or travel environment encountered (for a discussion, see Hunt and Abraham, 1997).

Computational Requirements:

Discrete choice models can be estimated using a desktop microcomputer with specialized software such as ALOGIT.

User Skill/Knowledge:

A knowledge of statistical analysis and discrete choice modeling techniques is required, in addition to familiarity with sources and methods of collecting survey data.

Assumptions:

Discrete choice models assume that choices made by individuals can be predicted based on a limited set of quantifiable factors and that people are essentially rational decision-makers who seek to make choices that maximize their utility. Furthermore, the relationship between the underlying factors and the probability of the individual choosing a particular alternative is assumed to bear a particular functional form (i.e., a logit function).

Facility Design Factors:

A range of facility design factors can be included in a discrete choice model. The inclusion of design factors is generally limited by:

1. For stated-preference surveys, the need to keep hypothetical alternatives simple and understandable to the respondent.

2. For revealed-preference surveys, the resources required to collect data describing existing facilities. Also, design factors are limited to those that currently exist in the realworld.

Output Types:

Possible outputs include:

- The probability of an individual making a particular choice given particular levels of variables (such as availability of bicycle parking, presence of a sidewalk, etc.)

- Elasticities indicating the percent change in the variable being predicted (i.e., probability of choosing a mode) for a given change in one of the independent variables, holding the other variables constant.

- Total number/percent of people expected to change behavior, if results of the model are aggregated over a population.

Real- World Examples:

Work Trip Mode Choice:

Kocur, Hyman, and Aunet (1982) describe the development of work-trip mode choice models for the Wisconsin Department of Transportation (WisDOT). In the late 1970s and early 1980s, WisDOT developed a series of mode-choice models to consistently assess transportation policy issues across urban areas in the State. Work-trip logit mode choice models are developed for four sets of metropolitan areas in Wisconsin based on the results of stated and revealed-preference surveys. Bicycle and walk are included as separate mode choices. Bicycle facility variables include distance to work, existence of a bike lane (yes or no), street surface (smooth or rough), and traffic (busy or quiet). Pedestrian facility variables include distance to work, presence of sidewalks, and season (summer or winter). The models are used to estimate the effects of various policies on mode split. Addition of marked bicycle lanes to all streets in the cities studied was estimated to increase total summertime bicycle trips by 39 percent. Allowing pavement to deteriorate from smooth to rough was estimated to reduce summertime bicycle work trips by 42 percent.

Transit Access Mode:

Discrete choice models have been developed in a number of areas to predict transit access mode. A study for the Chicago Regional Transit Authority *(Wilbur Smith Associates, 1996)* estimates the effects on transit mode choice access of various improvements to bicycle and pedestrian facilities in station areas, based on estimation of a discrete mode choice model from both revealed-preference and stated-preference survey data. For more information, see separate entry on "Discrete Choice Models – Transit Access."

Taylor and Mahmassani (1996) developed a discrete choice model based on a hypothetical-choice stated-preference survey to assess preferences for work trip mode choice (auto, park-and-ride, or bike-and-ride). Facility factors include on-street bicycle facility type, bicycle parking facility type, and access distance to transit. Only relative utilities are reported, and the model is not used to predict changes in total mode use as a result of facility changes.

Loutzenheiser (1997) developed a discrete choice model of transit mode choice access based on Bay Area Rapid Transit passenger surveys and station area characteristics. Urban design and station area characteristics were found to be secondary to individual characteristics in determining the choice to walk. (Station area variables include nearby arterials and freeways; grid pattern; population density; and type and mix of land uses. Descriptors were developed using GIS techniques.)

Inclusion of Attitudinal and Perception Factors:

Additional studies have focused on determining the effect of users' attitudes and perceptions on the choice to walk or bike. These studies have also included rudimentary variables describing the quality of bicycle and/or pedestrian facilities.

Katz (1996) modeled demand for commuter bicycle use in two steps: (1) the choice to participate (bicycle) is modeled, through factor analysis and logit regression, based on attitudes and personal characteristics; and (2) mode choice is modeled through discrete choice (logit) models which include attitudes, personal characteristics, and structural factors (cost, distance, etc.). Bicycle facility measures include bicycle cost, trip distance, availability of showers and parking at the trip end, and percent of trip on a bike path. Elasticities for the bicycle mode are -0.88 for trip distance, +0.58 for percent of trip on bike path, and +0.26 for car cost. Inclusion of attitudinal factors is found to significantly improve model fit. Data are based on telephone and in-person surveys and choice experiments. An extensive discussion and literature review of the behavior modeling issues and techniques relevant to bicycle travel modeling is also included.

Kitamura, Mokhtarian, and Laidet (1997) conducted stated-preference surveys to determine the relative influence of socioeconomic, attitudinal, and neighborhood characteristics on travel behavior. Discrete choice models were developed to predict mode choice and total number of trips by mode. Facility variables included presence of sidewalks and bike paths as well as perceptions of whether streets are pleasant for walking or bicycling.

Noland (1995) developed multinomial logit models which relate use of a mode to perceptions of risk and convenience of that mode (perceptions of cost, comfort, and relevant personal variables are also included). Risk and convenience perceptions were measured based on surveys of bicyclists and of the general population. Modes include auto, transit, bicycle, and walk. The model was used to evaluate the general effect of policy variables on mode split. Elasticities were developed with respect to bicycle convenience, comfort, parking availability, competency, and lack of shoulders, as well as auto cost, convenience, and comfort. Sample enumeration was used to predict future mode splits as a result of policy changes. "Short-run" and "long-run" elasticities and mode splits were developed, which assume that many people do not have a choice of modes in the short run, but that in the long run different urban form policies and residential location decisions could allow everyone a choice of modes.

Mode Choice in Travel Demand Models:

Discrete choice models have been widely used to predict mode choice for work trips and other types of trips in the development of regional travel models. However, these models rarely include bicycle or walking trips as separate modes. For a discussion of models that do include bicycle and walking trips, see entry for "Regional Travel Models."

Route Choice Models:

Discrete choice models have also been applied to predicting route choice or facility preference as a function of route/facility characteristics (see "Discrete Choice Models – Route Choice," Method 2.6).

Publications:

Ben-Akiva, M. and S.R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand.* Cambridge, MA: The MIT Press, 1985.

Horowitz, Joel L.; Frank S. Koppelman and Steven R. Lerman. *A Self-instructing Course in Disaggregate Mode Choice Modeling.* Prepared for the Urban Mass Transit Administration (now Federal Transit Administration), Washington, DC, December 1986.

Loutzenheiser, David R. *Pedestrian Access to Transit: A Model of* Walk *Trips and their Design and Urban Form Determinants Around BART Stations.* Transportation Research Board, 76th Annual Meeting, Washington, DC, January 1997.

Katz, Rod. *Demand for Bicycle Use: A Behavioural Framezuork and Empirical Analysis for Urban NS W,* Doctoral Thesis, The Graduate School of Business, The University of Sydney, Sydney, NSW, Australia, December 1996.

Kitamura, Ryuichi; Patricia L. Mokhtarian and Laura Laidet. *A Micro-Analysis of Land Use and Travel in Five Neighborhoods in the Sun Francisco Bay Area.* Transportation Vol. 24, No. 2, May 1997.

Kocur, George; William Hyman and Bruce Aunet. *Wisconsin Work Mode-Choice Models Bused on Functional Measurement and Disaggregate Behavioral Data.* Transportation Research Record 895, 1982.

Noland, Robert B. and Howard Kunreuther. *Short-Run and Long-Run Policies for Increasing Bicycle Transportation for Daily Commuter Trips.* Transport Policy, Vol. 2, No. 1, 1995.

Taylor, Dean and Hani Mahmassani. *Analysis of Stated-Preferencesfor Intermodal Bicycle-Transit Facilities.* Transportation Research Record No. 1556, 1996.

Wilbur Smith Associates. *Non-Motorized Access to Transit: Final Report.* Prepared for Regional Transportation Authority, Chicago, IL, July 1996.

Evaluative Criteria: How Does It Work?

Performance:

Kocur, Hyman, and Aunet (1982), in calibrating their behavior models based on actual behavior, found that the calibration coefficients are "larger than we would ideally like to see, but they indicate a relatively good correspondence between the experimental models and actual behavior."

The performance of the other models discussed here has not been evaluated.

Use of Existing Resources:

Development of a discrete choice model usually requires new data collection efforts. In some cases, it may be possible to transfer coefficients from a model developed in one area to other areas, eliminating the need for local data collection. However, this implies that the two situations are similar with respect to factors not included in the model.

Travel Demand Model Integration:

Discrete choice models are widely used to predict mode choice in existing travel demand models. It is a logical extension of existing practices to include non-motorized travel in this step. The added complication and data requirements, however, have so far limited the inclusion of non-motorized travel in most models.

Applicability to Diverse Conditions:

Determining the variables to include in a model and the required data collection efforts represents a-tradeoff. The more specific the variables to the improvement being analyzed, the more accurate the results in analyzing that improvement. On the other hand, the model will be less applicable in different situations, and if a different improvement is to be analyzed, new data collection and modeling efforts may be required. Models with general environment or facility descriptors may have broader applicability but will be less suited for analyzing the impacts of a particular improvement. As an example, a model of bicycle choice may be estimated regionally using a variable of "miles of bicycle lanes available." Such a model may be of general use for evaluating and comparing facility improvement policies. For evaluating the effects of a specific improvement, however, it may not be as accurate as a model based on a survey in one locality which includes as a variable "bike lanes from point A to point B on street X."

Kocur, Hyman, and *Aunet* compared coefficients among the four sets of cities of varying sizes for which they were developed. They found that "most of the coefficients show relatively little variation across cities, which suggests that transferability of these coefficients among urban areas is a possibility."

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

See "Applicability to Diverse Conditions" above.

Ease-of-Use:

A knowledge of discrete choice modeling techniques is required, in addition to familiarity with sources and methods of collecting survey data.

Demand Estimation:

2.6 Discrete Choice Models: Route Choice

Descriptive Criteria: What is It?

Categories:

☒ Bicycle • I Pedestrian ☒ Facility-Level ☐ Area-Level

Authors and Development Dates:

Bovy and Bradley (1985); Hopkinson and Wardman (1996); Hunt and Abraham (1997); Hyodo, Suzuki, and Takahashi (1998).

Purpose:

Discrete choice modeling techniques can be applied to predicting bicycle route choice as well as mode choice. Discrete route choice models have a number of possible applications:

- Determining the relative preferences of bicyclists for different route characteristics, e.g., separate path, bicycle lanes, or mixed traffic. One advantage of discrete choice models over other methods is that the tradeoffs between attributes can be quantified (for example, a change in pavement quality from "fair" to "good" can be equated to a travel time improvement of X minutes).

- Developing elasticities, which can be used to relate the change in a particular factor to the expected percent change in number of users.

- Predicting actual route choice on a bicycle or pedestrian network. The output would be the distribution of trips over the network, given a set of origins and destinations. A route choice model developed by Hunt and Abraham (1997) is being applied to a network in Edmonton, with the ratios among coefficients for each facility type being used to weight travel time in the mode choice submodel (see "Regional Travel Models" discussion). Discrete route choice models may be a key element in future development of bicycle demand forecasting models, particularly in developing models which predict both mode and route choice as a function of route characteristics.

Structure:

Three of the four references reviewed here use a logit model to predict route choice as a function of route characteristics and other factors. The resulting coefficients on the route characteristics are used to compare the relative importance of these characteristics.

Hyodo, Suzuki, and Takahashi (1998) use a slightly different approach. Bicyclists are surveyed and asked to map their trips on a road network. The frequency of actual trips on each link is compared to the frequency of trips under a shortest-distance path assignment, and parameters which affect the "cognitive travel time" are estimated based on facility design factors. The authors include sidewalk width (under or over 2.5 m) and street type (dummy for a shopping arcade closed to traffic) as facility design factors, although other factors could be included if data were available. The "genetic algorithm" method, a specialized technique for parameter estimation, is used to estimate parameter values. The authors' method is unique in that it uses revealed-preference data (observed trip routes) and link-specific characteristics to derive parameters which can be used to include facility characteristics in a route choice model. However, it also points out the computational and methodological difficulties in estimating more than one or two parameters. While including design factors improves the model fit compared to a simple shortest-path assignment, the method has not yet been developed for use in demand forecasting.

Calibration/Validation Approach:

If the route choice models were applied to predicting network flow distributions, predicted distributions could be compared to actual flows as determined from counts.

Inputs/Data Needs:

The four models reviewed here are based on data from stated-preference surveys of bicyclists. Respondents are asked to choose between pairs of hypothetical bicycling links with specified attributes.

Potential Data Sources:

Development of a discrete route choice model usually requires stated-preference survey data. Revealed-preference data could also be used but would require extensive real-world data collection on facility characteristics and user trip patterns, although GIS techniques and data bases may make this easier in the future. Estimation of coefficients using revealed-preference data also presents some technical problems (see Hyodo, Suzuki, and Takahashi, 1998). Other problems with the use of revealed-preference data are discussed in Hunt and Abraham (1997).

Computational Requirements:

See general entry for "Discrete Choice Models," Method 2.5.

User Skill/Knowledge:

Requires knowledge of discrete choice modeling and stated-preference survey techniques.

Assumptions:

See general entry for "Discrete Choice Models," Method 2.5.

Facility Design Factors:

Boy and Bradley:

- Facility type (physically separated, reserved on-street, non-existent).
- Surface quality (smooth, moderate, rough).
- Traffic level (light, moderate, heavy).
- These three design factors are traded off against travel time (9, 12, or 15 minutes).

Hunt and Abraham:

- Secure parking.
- Availability of showers.
- Facility type (mixed traffic, bike lanes, or bike paths shared with pedestrians). The interactions of facility type variables with the experience and comfort levels of the bicyclist are given particular attention.

Hyodo, Suzuki, and Takahashi:

- Sidewalk width; and
- Dummy variable for a pedestrian mall.

Output Types:

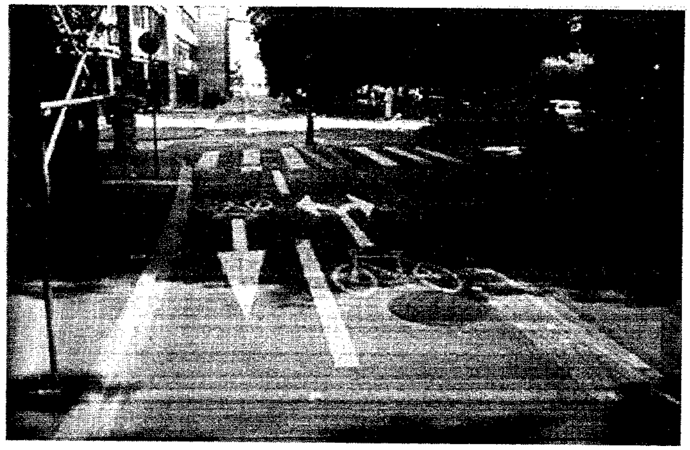
Outputs include the relative importance of various route attributes.

Real- World Examples:

Boy and Bradley (1985) used stated-preference surveys to develop a discrete route choice model. Route factors included facility type, surface quality, traffic level, and travel time (each described qualitatively at three levels).

Hopkinson and Wardman (1996) used stated-preference techniques to obtain valuations of improvements to cycle facilities, forecast the effects of such facilities on route choice, and provide a partial cost-benefit analysis of alternate bicycle routes.

Hunt and Abraham (1997) developed a discrete route choice model based on a hypothetical-choice stated-preference survey of cyclists in Edmonton, Canada. Facility factors included time spent cycling on three different facility types and the availability of showers and secure bicycle parking. Socioeconomic data and indicators of experience and comfort level were also used in model development.



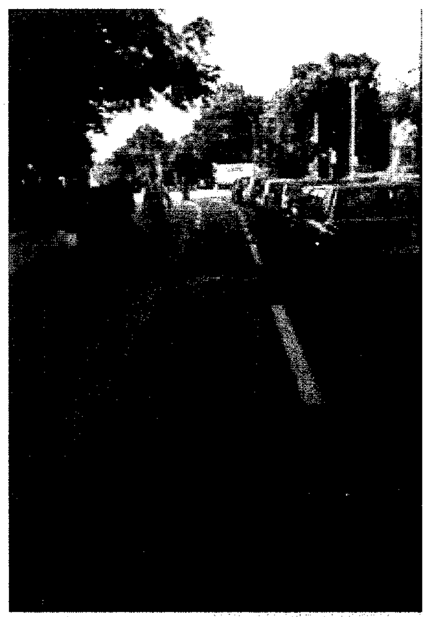


Figure 2.6 What are bicyclists' relative preferences for riding on separate paths or in bicycle lanes?

Hyodo, ***Suzuki,*** and *Takahashi (1998)* proposed a bicycle route choice model in which facility characteristics (e.g., road width or sidewalk) affect the impedance function in route choice. Development of the model was based on a survey of bicyclists in which they were asked to map their trip on a network. Parameters were estimated based on actual vs. minimum-path routes, using the Genetic Algorithm method.

Contacts/Source:

John Abraham: T. J. Modeling, Calgary, Alberta, Canada.

John Hunt: University of Calgary, Department of Civil Engineering, Calgary, Alberta, Canada.

Tetsuro Hyodo: Tokyo University of Mercantile Marine, Tokyo, Japan.

Publications:

Bovy, Piet H.L. and Mark A. Bradley. *Route Choice Analyzed with Stated-Preference Approaches.* Transportation Research Record 1037 (1985).

Hopkinson, P. and M. Wardman. *Evaluating the Demand for New Bicycle Facilities.* Transport Policy, Vol. 3 (1996).

Hunt, J.D. and J.E. Abraham. *Influences on Bicycle* Use. Submitted for presentation at the 1998 Transportation Research Board Annual Meeting, July 1997.

Hyodo, Tetsuro; Norikazu Suzuki and Yoji Takahashi. *Modeling Bicycle Route Choice Behavior on Describing Bicycle Road Network in Urban Area.* Presented at the 1998 Transportation Research Board Annual Meeting, Paper #980353, January 1998.

Evaluative Criteria: How Does It Work?

Performance:

No information is available.

Use *of Existing Resources:*

Survey and modeling efforts are required.

Travel Demand Model Integration:

Route choice models have not widely been integrated with travel demand models. However, bicycle route choice models could theoretically be included in the traffic assignment step. Hunt and Abraham note that their route choice model is being applied to the development of a network-based travel demand model in Edmonton, with the ratios among coefficients used to develop a utility function for bicycling in the mode choice submodel.

Discrete route choice models may be a key element in future development of bicycle demand forecasting models, such as in developing combined models which predict both mode and route choice as a function of route characteristics.

Applicability to Diverse Conditions:

The results of current route choice models have been based on generic, hypothetical route characteristics and thus should be applicable to various locations and conditions. Nevertheless, the survey responses may to some extent have been. conditioned by the environment with which the respondents are familiar, so transferring results should be done with caution.

The validity of these models can be assessed by comparing the relative preference results to results obtained from other studies. Bovy and Bradley found consistency between their results and earlier studies by Axhausen (1984), and also found a reasonable amount of internal consistency comparing the results of different evaluation methods used in their study.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

See entry for "Discrete Choice Models," Method 2.5.

Ease-of-Use:

Generally requires survey efforts and a knowledge of discrete choice modeling.

Demand Estimation:

■ 2.7 Discrete Choice Models: Transit Access

Descriptive Criteria: What is It?

Categories:

❑ Bicycle ⊠ Pedestrian Cl Facility-Level ❑ Area-Level

Authors and Development Dates:

Wilbur Smith Associates (1996)

Purpose:

This method describes a realworld application of discrete choice modeling to predict bicycle and pedestrian mode share for transit access trips for the Chicago Transit Authority (CTA) and Metra rail systems in Chicago.

Structure:

Two discrete choice models are estimated, one for access mode to Metra (commuter rail) and one for access mode to CTA (rapid rail). A nested logit form is used, for which the first-level choice is motorized vs. non-motorized, and the second-level choices are car vs. bus and walk vs. bike. (For a discussion of logit modeling techniques including nested logit models, see Ben-Akiva and Lerman, 1985.)

The models include the following variables:

- Travel Time Variables:
  - Main transit or auto trip;
  - Egress;
  - Walk access;
  - Bus access;
  - Bike access; and
  - Auto access.
- Parking avail. (auto);
- Parking cost;
- Other costs;
- Number of buses;

- Bike improvements (seven variables – see "Facility Design Factors" below); and
- Walk improvements (seven variables – see "Facility Design Factors" below).

To estimate changes in mode share based on model results, sub-models were developed based on distance from transit station. The areas around stations were divided into five concentric rings in increments of a 0.8-km radius. Population density was estimated for each ring by classifying the station as one of five types of land use: dense urban, urban, dense suburban, suburban, or other. These submodels were developed because of the importance of access distance in choice of access mode. For the other variables, average values were used when estimating the mode choice impacts of the various bike or walk improvements.

Calibration/Validation Approach:

The model coefficients were adjusted so that current access mode shares more closely matched access mode shares as reported from two sources: (1) the Metra mode of access survey for Metra stations; and (2) the intercept survey for CTA stations.

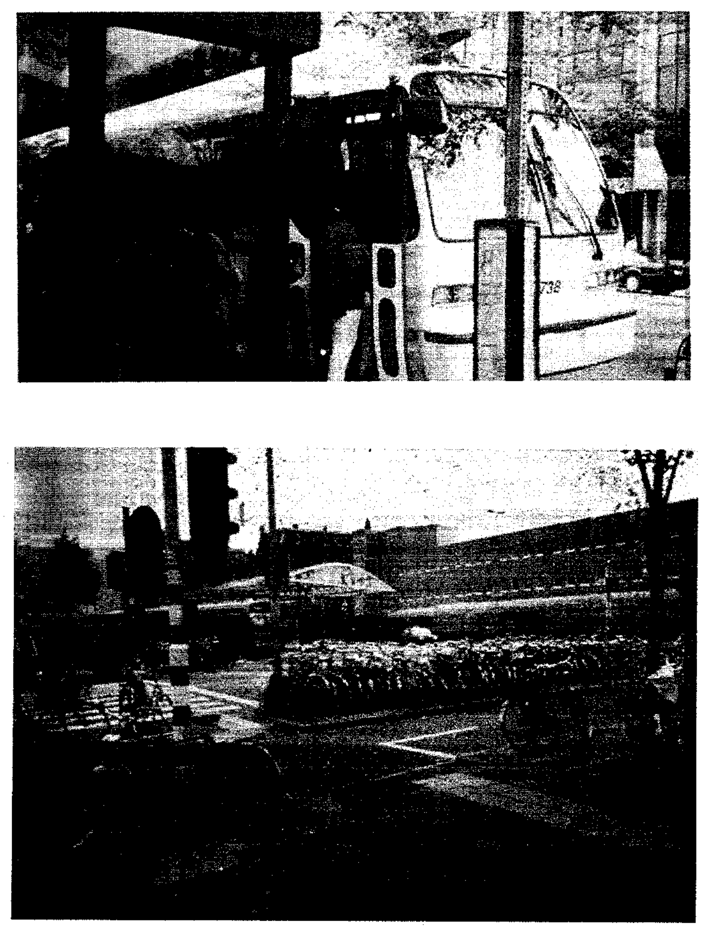


Figure 2.7 Discrete choice modeling can be used to predict bicycle and pedestrian mode share for transit access trips.

Inputs/Data Needs:

Two new data sources were used for developing the model:

1. An intercept survey of transit users. Respondents were asked for trip characteristics (modes, times, length, cost, and purpose), reasons for not choosing alternative modes, and socioeconomic characteristics. To use the results in model development, characteristics of alternative modes had to be assumed based on the information given by the respondent.

2. A stated-preference survey using IVIS (Interactive Video Interview Station) techniques. IVIS equipment was set up at workplaces in downtown Chicago; respondents included drive-alone as well as transit commuters. Trip characteristics and socioeconomic data were collected. In addition, respondents were given a series of hypothetical choices which required them to make tradeoffs between travel time, travel cost, parking costs, and access improvements. Video images were used to help describe bicycle and pedestrian access improvements.

An existing data source, the Metra mode of access survey, was used to calibrate the model (see "Calibration/Validation Approach," above) The existing regional household survey performed by the Chicago Area Transportation Study (CATS) was considered for calibration but was felt to be less reliable for the purposes of this study.

Potential Data Sources:

See "Inputs/Data Needs," above.

Computational Requirements:

Discrete choice models can be estimated using a desktop microcomputer with specialized software.

User Skill/Knowledge:

The model requires knowledge of stated preference surveys and discrete choice modeling.

Assumptions:

See entry on "Discrete Choice Models," Method 2.5.

Facility Design Factors:

The following factors were included in the model:

- Debris;
- Parking;

- Curb lane; and
- Slow traffic.

In addition, the presence of paths, lanes, and routes were tested as variables but were not included because of lack of statistical significance.

The following walk improvements were included in the model:

- Sidewalk;
- Recreation path;
- Slow traffic;
- No turn on red;
- Crosswalk;
- Pedestrian lights; and
- Walk island.

Output Types:

An alternatives analysis was conducted to estimate the change in transit access mode share as a function of various combinations of improvements. The five alternatives tested were labeled as:

- Present conditions;
- Bicycle parking;
- Transportation Systems Management (TSM)/low capital;
- Pedestrian improvements; and
- High capital.

The mode share effects of other improvements included in the model, both individually and in combination, could also be easily estimated.

Real-World Examples:

Wilbur Smith Associates (1996) developed this model and applied it to the CTA and Metra rail systems in Chicago.

Contacts/Source:

Joe Moriarty, Chicago Regional Transit Authority, Chicago, IL. (Models were developed for the Chicago Regional Transit Authority by Wilbur Smith Associates, in conjunction with Resource Systems Group, Applied Real Estate Analysis, and the League of American Bicyclists.)

Publications:

Wilbur Smith Associates. *Non-Motorized Access* to Transit: Final *Report*. Prepared for Regional Transportation Authority, Chicago, IL, July 1996.

Evaluative Criteria: How Does It Work?

Performance:

The accuracy of the model predictions has not yet been tested.

Use of Existing Resources:

This method requires new data collection and analysis efforts.

Travel Demand Model Integration:

The project report recommends that the access to transit model be linked to the main Chicago area mode choice model. This will give the Chicago RTA a more comprehensive planning tool for evaluating the mode choice and ridership impacts of multiple changes in the transportation system.

Applicability to Diverse Conditions:

The models were meant to be representative of the CTA and Metra systems as a whole; use of the model to predict mode choice impacts at specific stations is recommended only with caution, since other factors which vary from station to station may not be captured in the model.

Similarly, it is possible that the models estimated here could be transferred to other transit systems. However, conditions external to the model would have to be assumed similar to Chicago area conditions.

Usage in Decision-Making:

The model has been used for prioritizing stations, selecting case study locations, identifying design improvements, and estimating the cost-effectiveness of improvements.

Ability to Incorporate Changes:

The effects of different levels of facility design factors already included in the model can easily be estimated. Estimating the effects of new facility design factors would require additional survey efforts.

Ease-of-Use:

Development of the model requires knowledge of stated-preference surveying and discrete choice modeling. Once the model is developed, it can be applied to different data sets using a spreadsheet.

Demand Estimation:

❑ 2.8 Regional Travel Models

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☒ Pedestrian ☒ Facility-Level ☒ Area-Level

Purpose:

Regional travel models use existing and future land use conditions and transportation network characteristics, in conjunction with models of human behavior and other travel characteristics, to predict future travel patterns. Regional travel models can be used to predict the impacts of improvements to the bicycle and pedestrian environment on levels of utilitarian (non-recreational) bicycle and pedestrian travel, as well as on motorized vehicle trips, vehicle-miles of travel (VMT), and emissions.

The basis for regional travel models is the division of the urban area into zones, which usually correspond to census tracts, and the definition of a network of transportation facilities connecting the zones. The inputs are proposed or projected future transportation systems and forecast population and employment by zone. A four-step process is used:

1. Total trips that start and end in each zone are predicted.
2. These trips are distributed between pairs of zones.
3. The trips are allocated among the available travel modes (usually auto and transit).
4. The trips are assigned to specific facilities included in the highway and transit transportation networks.

The data for predicting travel behavior are primarily based on surveys of households to track a sample of travel patterns. Trips are generally predicted separately by trip purpose (i.e., work, shopping, other) and then aggregated into total trips on the network. The primary emphasis in modeling is on peak-hour travel to determine the number of vehicles using each transportation facility at the time when demand is greatest.

Regional travel models and their associated data collection‘efforts have traditionally been oriented toward predicting automobile and to a lesser extent transit trips, and have generally not included non-motorized travel modes. Even if non-motorized modes were to be included as alternatives, existing data on non-motorized travel and network characteristics are often insufficient or of poor quality, and the models have a zonal structure and level of network detail that is too coarse for analyzing short trips, Recreational and non-peak-period travel, which can be important components of non-motorized facility use, are also poorly developed areas of travel modeling.

A number of efforts have been made recently to overcome these limitations and incorporate non-motorized travel into recent travel models. In some metropolitan areas of the United States, Canada, and Europe, household travel surveys have been redesigned to include bicycling and walking trips, and models have been modified to incorporate bicycle and/or pedestrian modes as alternatives and describe the characteristics of the bicycle or pedestrian network. Inclusion of non-motorized modes has the potential not only to predict non-motorized trip choice as a result of future changes, but also to predict changes in automobile and transit travel as a result of these changes and improve the overall accuracy of the models.

In addition to the full inclusion of non-motorized modes in regional travel models, quick-fix methods can be used to approximate the potential vehicle trip reduction effects of transportation and land use strategies, by manually adjusting trip generation rates, auto ownership levels, or mode choice factors. Such sketch planning methods can be useful when model shortcomings and time and resource constraints limit the opportunity for more complete model development or refinement. Finally, regional travel demand models can provide information, such as trip lengths and distributions by origin/destination and purpose for all modes, that is useful for other non-motorized travel planning activities or forecasting methods.

Structure:

Most regional travel models that incorporate non-motorized travel do so through the mode choice step. Bicycling and walking are included as options along with auto and transit in logit models of mode choice.’ Bicycle and walk modes may be treated separately or may be combined as one option (non-motorized) because of insufficient data to treat the modes separately. Also, some models distinguish between auto and walk access to transit, but do not include walking as a separate mode choice for an entire trip.

All of the models predicting non-motorized mode choice include some combination of travel time, distance, and cost variables to predict mode choice. Some also include other variables that describe the quality of the non-motorized transportation facilities or network for bicycling or walking. Non-motorized network characteristics are incorporated through one of the following two methods:

1. Zone-level factors describing the quality of the area’s environment for walking and/or bicycling. These may include population and employment density as well as a pedestrian or bicycle environment factor which describes the relative attractiveness of, the area for walking or bicycling based on physical characteristics of the area (presence of sidewalks, pedestrian street crossings, hills, etc.).

2. Network-level variables describing the presence and/or quality of bicycling or walking facilities. The non-motorized network can use the existing model’s road network as its basis. Each link can then. be coded” with bicycle or pedestrian-specific variables (i.e.,

[2] Logit models are mathematical functions that relate the probability of choosing a specific alternative to characteristics, such as time and cost, of that alternative and of competing alternatives.

whether there is a bike path). Additional bicycle or pedestrian-specific links (such as a non-motorized trail) can also be added to the network.

As an alternative or supplement to consideration of mode choice, models can be modified to predict the choice of routes by non-motorized travelers as a function of route characteristics. This can only be done if the model includes a network of non-motorized facilities, as described above. The characteristics of the facilities can then be used to predict the routes followed by bicyclists or pedestrians between each pair of zones, once the total number of bicycle or pedestrian trips between each pair of zones has been determined by the mode choice model. Some models have specifically been developed to predict route choice as a function of the bicycle network, where total bicycle trips are based on assumptions exogenous to the model (see entries for "Bicycle Travel Models," Methods 2.9 and 2.10).

Other specific approaches to incorporating the bicycle and pedestrian modes into regional travel models are described under "Real World Examples" below.

In addition to directly incorporating non-motorized travel into regional travel models, travel model data or output (in the form of zone-to-zone trip tables for all modes, including non-motorized) can be adjusted to estimate non-motorized trips and a corresponding reduction in motorized trips between each pair of zones. Specific examples are given in Chesapeake Bay Foundation (1995) and Clark (1997) and are also described under "Real World Examples" below.

Calibration/Validation Approach:

Mode choice models are developed using standard statistical procedures for calibrating and validating these models. Selection of the final mode choice model may include extensive testing of a variety of variables and model forms. Model validation is performed by comparing predicted trips for various strata (geographic area, household income, etc.) with the actual number of trips from the household travel survey.

Inputs/Data Needs:

Travel modeling efforts require extensive data, including:

- Population, employment, and land use data by traffic analysis zone;
- Personal and household travel characteristics as determined from household travel surveys; and
- Roadway and transit networks.

To incorporate non-motorized travel into regional travel models, additional data are required on non-motorized travel characteristics and on the non-motorized transportation network. In particular:

1. The household travel survey(s) used to develop the model must include data on bicycle and pedestrian trips. These modes have frequently been neglected in standard travel surveys although incorporation is becoming more common. Experience suggests that

surveys must be worded carefully to obtain complete information, particularly with respect to short-walk trips which are frequently not reported. In addition, a larger sample size and/or specialized sampling techniques may be required to obtain a sufficient sample size for non-motorized trips, particularly if bicycles and pedestrians are to be modeled as separate modes rather than as a single mode.

2. Data on the bicycle and/or pedestrian network are required if the model is to be sensitive to the effects of network improvements. In particular, local field data collection may be required either to construct environment factors or to add bicycle or pedestrian characteristics or links to the road network.

3. If mode or route choice is to be modeled based on facility characteristics, relative preferences for each type of facility must be developed and related to travel time/distance. This can be done either through special survey efforts or by borrowing or transferring results from studies performed in other areas.

Potential Data Sources:

In addition to the data sources already compiled for standard travel modeling efforts, the following data sources might be useful for developing bicycle or pedestrian descriptors at the zonal level:

- Census TIGER files for developing topological descriptors of local road networks. Hsaio (1997) and Wineman (unpublished) have both used TIGER files to evaluate the connectivity of networks for pedestrian travel (discussed under entry on "Geographic Information Systems," Method 2.18)

- Local inventories of pedestrian facilities and/or bicycle facilities, although such inventories may not always exist. Data storage and analysis can be enhanced through the use of GIS applications.

Computational Requirements:

The travel modeling process is computationally intensive but can be performed using desktop microcomputers with appropriate software.

User Skill/Knowledge:

A familiarity with travel demand modeling techniques is required.

Assumptions:

To date, only a few factors influencing the choice to bike or walk have been incorporated in regional travel models. Trip distance or time is the primary consideration, with trip purpose, personal characteristics, or general environment factors considered in a few cases. One general assumption behind the mode choice component of traditional travel models is that mode choice can be predicted primarily as a function of only travel time and travel cost. In the case of both pedestrian and bicycle travel, however, this has been demonstrated not to be the case, and a variety of environmental and personal factors are perhaps of much greater significance. Exploration of these factors, and how they can best be incorporated into the modeling framework, is necessary before travel models will yield significant useful information on the effects of bicycle and pedestrian design actions.

Some practical problems with including non-motorized travel in current models include insufficient data on trips by these modes, insufficient basis for predicting non-motorized travel decisions, lack of information on non-motorized network characteristics, a zonal structure/level of detail which is too coarse for analyzing short trips, and inability to model recreational trips. Therefore, the results produced by these models are only rough

BEFORE

AFTER

Figure 2.8 Regional travel models can be used to predict the effects of improvements to the pedestrian environment on pedestrian travel, as shown here in Key West, Florida.

approximations and their performance for predicting future levels of non-motorized trip making as a result of improvements or policy changes has not yet been validated.

Facility Design Factors:

The most common method of incorporating facility design factors to date has been through the use of a Pedestrian Environment Factor (PEF), which is a composite index of a number of factors which are viewed as influencing the attractiveness of an area for walking. One modeling effort (the PROMO pivot-point model for the Washington, DC region) has expanded the PEF to include bicycling factors. The Portland PEF has been applied for modeling in Portland, OR, Sacramento, CA, and adapted for use in the Washington, DC region by adding a bicycle component. A pedestrian-bicycle environment factor (PBEF) has also been developed in Montgomery County, MD.

Portland's PEF includes four elements: (1) sidewalk availability; (2) ease of street crossing; (3) connectivity of street/sidewalk system; and (4) terrain. Montgomery County's PBEF includes five elements: (1) extent of sidewalks; (2) land use mix; (3) building setbacks; (4) transit-stop conditions; and (5) bicycle infrastructure. For a description of how these elements are combined into an overall factor, see entry for "Environment Factors," Method 2.17.

The travel model for the Edmonton area classifies each link of the network by type of bicycle facility: bike path, bike lane, or mixed traffic. The relative attractiveness of each facility type is used to weight the total travel time between two zones. This general approach could be applied using other facility design factors, given the following: (1) information on the facility design factor for each link in the network; and (2) information on the relative tradeoffs made by cyclists between these facility design factors and travel time.

Output Types:

The output of the travel modeling process is the number of bicycle and pedestrian trips originating in each traffic analysis zone (total or by trip purpose), and the distribution of these trips between pairs of zones. For the base year (existing conditions), the model is calibrated so that these trips match as closely as possible the actual generation and distribution of trips as reported in the household travel survey. The expected number of trips in some future year can then be predicted-based on projected changes in population; employment; land use; demographic characteristics; and the roadway, transit, and bicycle networks.

Real- World Examples:

The following information is based on Stein (1996), informal communication with modelers, and other sources as noted. Approaches to incorporating non-motorized travel in existing travel models are summarized in table 2.1.

Edmonton, Canada. The Edmonton Transport Analysis Model recently developed for the Edmonton, Canada region (Hunt, Brownlee, and Doblanko, 1998) includes both walk and bicycle as separate modes and also includes bicycle network characteristics in determining mode choice. Links in the network model can be coded in three ways: bicycle path, bicycle lane, or mixed traffic. A coefficient in the mode choice model is estimated for bicycle

Table 2.1 Inclusion of Non-Motorized Modes in Regional Travel Models

Region	Modes				Steps of Modeling Process			Network Characteristics	
	Bicycle	Pedestrian	Combined	Walk to Transit	Mode Choice	Route Choice	Other	Environment Factor	Bike/Ped Facilities
Edmonton, Canada	X	X			X	X	X[1]		X
Portland, OR			X		X			X	
Sacramento, CA	X	X			X			X	
Montgomery Co., MD				X	X			X	
San Francisco, CA	X	X			X				
Los Angeles, CA			X	X	X				
Albany, NY	X	X			u	X		u	X
Leicester, UK (TRIPS/START)	X					X			X
Ipswich, UK (Quovadis)	X					X			X

[1] Utilities based on mode and route characteristics feed back to affect trip generation and trip distribution.
u = Under Development.

equivalent travel time, which is actual travel time adjusted by a factor representing the relative onerousness of bicycling on each facility type. Time-equivalent penalties by facility type are derived from a stated-preference survey of bicyclists (Hunt and Abraham, 1997), showing that for the average cyclist, one minute of bicycling in mixed traffic is as onerous as 2.8 minutes on bike paths or 4.1 minutes on bike lanes. The model has a number of other notable features, with trip generation, destination, time of day, and mode choice all based on logit models that were estimated using observations of individual travel behavior and applied at an aggregate (zonal) levels for 25 user groups and trip purposes. Composite impedances and accessibility measures feed backwards through each step, including to trip generation. Therefore, improvements to the bicycle network (i.e., addition of lanes or paths) can potentially affect total trip distribution and generation as well as mode choice. The model also estimates the composite utility of travel and therefore can be used to estimate the overall welfare benefits of an improvement to the bicycle network.

Portland, OR. Metro, the MPO for Portland, OR, included the non-motorized mode (walking/bicycling) as an option in the mode choice models for each trip purpose. Mode choice is predicted in two steps: first, motorized vs. non-motorized, and second, auto vs. transit for motorized trips. The motorized vs. non-motorized mode choice is a function of travel distance, ratio of cars to workers in the household, total employment within one mile of zone (a density measure), and a pedestrian environment factor (PEF). (Rossi, Lawton, and Kim, 1993).

Sacramento, CA. The Sacramento Area Council of Governments (SACOG) included pedestrian and bicycle modes separately in multinomial mode choice models for each trip purpose (attempts to develop a nested logit model were unsuccessful). A modified version of Portland's PEF is included in the transit, bicycle, and pedestrian mode choices; the PEF in the model is the product of the origin zone and destination zone PEFs. A durnmy variable is included for zones in the city of Davis, where university students and staff make large numbers of bicycle and walk trips (Stein, 1996; Metropolitan Transportation Commission, 1997).

Montgomery County, MD. The Maryland-National Capital Park and Planning Commission (M-NCPPC) developed a nested logit mode choice model for home-to-work trips which includes walk/bike access to transit as a submode to the transit mode. (Walk/bike is not estimated as a separate mode.) The model includes an index of pedestrian and bicycle friendliness; this is included at both the auto vs. transit and walk vs. auto access-to-transit levels of the model. (Chesapeake Bay Foundation, Environmental Defense Fund, et al., 1996).

San Francisco, CA. The Metropolitan Transportation Commission (MTC), the MPO for the San Francisco Bay Area, includes both walk and bicycle modes in their latest set of mode choice models. Bicycle and walk utilities are based on travel time, employment density (for work trip models), and dummy variables for the Stanford, Palo Alto, and Berkeley zones. Travel times are calculated using highway network distances and. an assumed speed of 19.3 km/h for bicycles and 4.8 km/h for pedestrians. The MTC models are noteworthy for the variety of trip purposes modeled. Separate trip generation, distribution, and mode choice models are developed for home-based work, home-based shop, home-based school (grade school, high school, and college), home-based social/recreation, and non-home-based trips. Some models have separate time coefficients for bicycle and walk. The MTC also attempted to include population density and area type (CBD, urban, suburban, etc.) in the mode choice models but these variables were not significant in predicting non-motorized mode choice. The MTC did not include the equivalent of a pedestrian and bicycle "environment factor." (Metropolitan Transportation Commission, 1995-1997).

Los *Angeles, CA*. The Southern California Association of Governments (SCAG), the MPO for the Los Angeles region, includes non-motorized travel (bicycle/walk) as a separate mode and also distinguishes walk vs. auto access to transit, for both local and express transit. Non-motorized utilities are based on composite time/cost, autos per capita, household income, population density, CBD of work, a variation on straight-line distance, and dummy variables for LA and Orange Counties.

Albany, NY. The Capital District Transportation Committee (CDTC) is incorporating bikes and pedestrians into its regional travel model effort using a two-pronged approach:

1. Incorporating bikes and peds into the mode choice component of the travel model. They have investigated other areas' efforts and plan to develop and collect a pedestrian and bicycle environment factor.

2. Developing separate networks for bikes and peds. These are based on the existing modeled road network, but with "preference-based speed coding." The bike network is coded with speeds between 0 to 16.1 km/h (0 for expressways, 16.1 for Class 1 bikeways and local streets; other links are based on a judgment of the attractiveness for bicycling). Pedestrian links may be coded as improved (4.8 km/h); unimproved but walkable (1.61 km/h); or "off." The speed factors are verified by showing model results for traffic assignment to a bicycle and pedestrian task force and asking them to evaluate the reasonableness of the assigned patterns.

These networks have already been developed and used for the purposes of prioritizing 34 bicycle and pedestrian projects in the most recent Transportation Improvement Program (TIP). Bicycle and pedestrian projects have both been evaluated separately from other projects and compared only among themselves because the types of benefits are very different than standard road and transit projects. Projects have been evaluated based on both modeled trip diversion from the mode choice model and on trip potential, in which the pedestrian network is loaded with all trips less than 3.2 km and the bicycle network is loaded with all trips less than 8.0 km. The total modeled response to a proposed project (measured in person-km of travel) is compared to its annualized cost to develop a cost-effectiveness measure which can be used for comparing bicycle and pedestrian projects with each other. For presentation of results to the planning committee, CDTC ranks each project as "high," "medium," or "low" with respect to three factors: market potential, cost-effectiveness, and safety. Each project is given a one-page write-up summarizing the results of the model runs and other project-related information.

CDTC plans in 1998 to integrate its bicycle and pedestrian network models with its traffic model so that there is feedback from the bicycle and pedestrian networks into the mode choice component of the traffic model.

Berkeley, CA. Ridgway (1995) suggests an approach to incorporating bicycle travel in a travel model developed for the city of Berkeley, CA by Fehr and Peers Associates of Lafayette, CA.

The approach includes three of the four elements of standard travel modeling: trip generation, trip distribution, and route assignment. The primary purpose of the model would be for use in prioritizing improvements based on projected levels of demand. Development of the model at the city level rather than the regional level allows a finer level of detail which is better suited for bicycle modeling purposes than the level of detail available in regional models.

Trip generation is based on total person-trip tables from the existing travel demand model, factored by bicycle mode splits by census tract based on regression analysis of tract-level characteristics. (Difficulties were encountered in developing a model that could predict bicycle mode splits at the tract level; see entry for "Aggregate Behavior Studies," Method 2.2.) Trip distribution would be conducted using a traditional gravity model, with the impedance factor based on travel distance and calibrated according to work-trip distributions from the 1990 census. Trip assignment would be based on travel distances on a traffic network modified for bicycling purposes. Development of a bicycle preferential rating system for links based on traffic volumes, facility types, and adjacent parking types is suggested but not described. Ridgway is currently developing and applying a similar approach for modeling bicycle travel in San Jose, CA.

In addition to directly incorporating non-motorized travel into regional travel models, travel model data or output (in the form of zone-to-zone trip tables for all modes, including non-motorized) can be adjusted to estimate non-motorized trips and a corresponding reduction in motorized trips between each pair of zones. Two approaches were identified:

1. Washington, DC area Proximity Mode Choice Model (PROMO):

   The PROMO model (Chesapeake Bay Foundation, 1995) is a sketch-planning model that predicts changes from the complete regional models for the Washington region to account for the effects of pedestrian and transit-oriented development. Starting with base-case travel behavior and conditions, walk mode share is adjusted for zones with transit-oriented development, under alternative scenarios, based on changes in employment density, a pedestrian environment factor (adopted from Portland's study), and transit service characteristics. Behavioral relationships are adopted from the Portland and Montgomery Co. models for home-based work trips and from modelers' experience for other trip purposes. PROMO is most readily used to adjust the number of vehicle trips generated at the zone level.

   PROMO has also been applied in New Jersey to evaluate pedestrian, bicycle, and land use improvements along the Route 1 corridor. The mode split impacts of a variety of improvements are analyzed, including pedestrian crossings (crosswalks, signal timing, and islands); sidewalk continuity and connectivity; and bicycle network connectivity and facilities. These are incorporated by adjusting the pedestrian environment factor for each zone.

2. Modification of trip tables in Bend and Pendleton, Oregon

   Clark (1997) describes a process to adjust vehicle trip tables in a travel demand model to account for future increases in bicycle and pedestrian trips. Existing trips are stratified by length and purpose, and adjustment factors which represent a potential percent increase in bicycle and pedestrian trips as a result of future improvements are applied to reduce the number of vehicle trips between each origin-destination (O-D) pair. The adjustment factors vary by trip purpose (home-based work, home-based other, and non-home-based); length (less than 0.8 km, 0.8 to 4.0 km, and 4.1 to 8.1 km); and mode (pedestrian and bicycling) and are based on local judgment.

Contacts/Source:

1,000 Friends of Oregon: http://www.teleport.com/~friends/Lutraq2/Docs.htm (Portland, OR).

David Clark: Kittelson Associates (Portland, OR).

John Hunt: University of Calgary, Department of Civil Engineering (Calgary, Alberta).

Carolyn Konheim: Konheim and Ketcham (Brooklyn, NY).

Chuck Purvis: Metropolitan Transportation Commission (Oakland, CA).

Michael Replogle: Environmental Defense Fund (Washington, DC).

Matthew Ridgway: Fehr and Peers Associates (Lafayette, CA).

Tom Rossi: Cambridge Systematics (Cambridge, MA).

Bill Stein: Metropolitan Service District (Portland, OR).

Publications:

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Konheim, Carolyn S., and M. Shahid Iqbal. Route 1 Corridor Collaborative Study (presentation). Konheim and Ketcham, Brooklyn, New York, 1998.

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Ridgway, Matthew D. Projecting Bicycle Demand: *An Application of Travel Demand Modeling Techniques* to Bicycles. 1995 Compendium of Technical Papers, Institute of Transportation Engineers 65th Annual Meeting, pp. 755-785, 1995.

Rossi, Thomas. T. Keith Lawton and Kyung Hwa Kim. *Revision of Travel Demand Models to Enable Analysis of Atypical Land Use Patterns.* Cambridge Systematics, Inc. and Metropolitan Service District, May 1993.

Stein, William R. *Pedestrian and Bicycle Modeling in North America 's Urban Areas: A Survey of Emerging Methodologies and MPO Practices.* Thesis: Master of City Planning and Master of Science, Georgia Institute of Technology, pp. l-28, March 1996.

Stein, William R. *Summa y of Bicycle Modeling Efforts at Portland Metro.* Metro Travel Forecasting Section, Portland, OR, November 1996.

Evaluative Criteria: How Does It Work?

Performance:

Incorporation of non-motorized travel has led to improvements in some regional travel models in terms of predicting auto vs. non-auto mode split. Portland Metro has found that inclusion of the PEF and non-motorized modes improves the fit of the model, reducing the tendency to over-predict auto trips in pedestrian-friendly areas. The PROMO model was found to be useful for evaluating the mode share effects of improving the pedestrian and bicycle environment. However, the PEF as applied in Sacramento was not statistically significant (MTC, 1997). Inclusion of dummy variables representing bicycle-friendly areas in California models has also improved model fit and could be used to indicate the mode choice impacts of improving non-motorized networks and policies.

Use of Existing Resources:

Non-motorized modes can be incorporated in existing travel model efforts, but require additional work to develop mode choice models. Additional data collection resources are also required if environment factors are to be developed.

Travel Demand Model Integration:

Yes.

Applicability to Diverse Conditions:

Model coefficients for bicycle and walk modes developed in one area can potentially be transferred to modeling efforts in other areas. The PROMO model in Washington, DC, for example, used coefficients taken from the Portland mode choice models. However, the validity of transferring these coefficients has not yet been established.

Usage in Decision-Making:

The Portland Metro and PROMO models have been used to evaluate the effects of future transportation, land use, and urban design alternatives on travel patterns, including walk/bike and transit mode shares and regional VMT.

Ability to Incorporate Changes:

Evaluating the effects of different policies or facility design factors requires re-running various elements of the travel demand model.

Ease-of-Use:

A familiarity with travel demand modeling techniques is required.

Demand Estimation:

❑ Bicycle Travel Models: QUOVADIS-BICYCLE

Descriptive Criteria: What is It?

Categories:

☒ Bicycle • I Pedestrian ❑ Facility-Level ❑ Area-Level

Authors and Development Dates:

DHV Environment and Infrastructure (no date)

Purpose:

QUOVADIS-BICYCLE is a bicycle network model developed by DHV Environment and Infrastructure of the Netherlands. The model can be used to simulate the effects of changes in the bicycle network on the distribution of flows over the network, It can also be used to simulate the effects of changes in socioeconomic characteristics on the generation and distribution of bicycle travel, and can be used to calculate various measures of accessibility and safety. The model is primarily a distribution model and is not intended to forecast changes in total bicycle travel as a result of network improvements.

Structure:

QUOVADIS-BICYCLE is based on QUOVADIS-CAR, an automobile network model, and bears many similarities to standard four-step transportation planning models. The primary exception is that the mode choice step is excluded. The basic steps are as follows:

1. Create a schematic representation of the bicycle network.
2. Calculate trip generation for each zone.
3. Distribute trips between zones.
4. Assign trips to the network.
5. Calibrate the model based on actual counts.
6. Run the model based on future socioeconomic and/or network conditions.

Steps 1 through 3 are repeated for four trip purposes (home-work, home-school, home-shop, and other) for three time periods (7 a.m. - 9 a.m., 9 a.m. - 4 p.m., and 4 p.m. - 7 p.m.). This produces 12 origin-destination trip tables, which are then aggregated into an overall trip table that is assigned to the network.

The details of the steps are as follows:

1. **Create a schematic representation of the bicycle network. QUOVADIS-BICYCLE** can import network data from car network models including Quovadis-CAR, Tranplan, TRIPS, and Proset, as well as ASCII data. The network can then be modified for bicycle purposes. The network consists of three elements: roads and streets (links), intersections, and connections of zones to the road network. Links can be assigned any of nine road categories (bicycle lane, bicycle track, mixed traffic, etc.) and different bicycle travel speeds can be assigned to each category (15 km/h is used as the default). Intersection delay (waiting time) is calculated based on car traffic, as read from the imported car traffic network. (The user can enter exceptional delays manually.) Speeds and distances for each zone's connection to the network can also be entered.

2. **Calculate trip generation for each zone.** Trip generation is based on bicycle trip rates derived from analysis by the Central Bureau of Statistics of the Dutch National Household Survey and local surveys. Default rates by time period and trip purpose have been developed based on the number of residents, pupil places at schools, shop employees, and other employees. Alternative data on trip generation rates can also be entered by the user, if such data are available.

3. **Distribute trips between zones.** Trips are distributed between zones using a resistance function based on the time required to travel by bicycle from one zone to the other. The resistance functions differ by the four trip purposes and are based on the actual distributions of bicycle trip distances as (presumably) determined from the national travel survey. Distances are converted to travel times using an assumed bicycling speed of 15 km/h, based on the shortest distance paths between zones. External trips (as determined from cordon counts) must be distributed manually. The option of intrazonal trips can also be specified, based on assumed intrazonal distances for each zone. These trips are not loaded onto the network.

4. **Assign trips to the network.** Assignment can be performed using either an all-or-nothing approach based on least-cost (travel time) paths or by stochastic assignment based on travel times. Interzonal travel times are based on link travel speeds plus intersection delays. There is also an option for selective assignment of traffic to certain links, paths, or screen lines.

5. **Calibrate the model based on actual counts.** Actual counts of bicycle movements can be used to adjust the O-D trip table. The calibration process is iterative. Counts used for calibration can be weighted based on the assumed reliability of the counts. The result of the calibration process is a correction matrix by which O-D tables from the distribution phases of future year plans should be multiplied.

6. **Run the model based on future socioeconomic and/or network conditions.** Once the model has been calibrated, it can be run with future socioeconomic data and/or an assumed future network to predict the distribution of traffic over the network under future conditions.

Calibration/Validation Approach:

See step 5 above.

Inputs/Data Needs:

The following data are required:

1. Socioeconomic data (number of residents, pupil places or students, shop employees, and other employees) on a zonal basis.

2. Bicycle trip rates by trip purpose and time of day.

3. Bicycle counts: internal counts for testing and calibration of the model, and cordon counts if external traffic is to be considered.

4. Network data. A basic bicycle network can be constructed from the existing road network used for modeling purposes (including car traffic volumes). Modification of this network requires some additional data collection on link characteristics relevant to bicyclists.

Potential Data Sources:

Some of the data sources and formats required for the model might not be readily available in the United States. In particular, data on pupil places is not a standard travel model input in most areas. Also, bicycle trip rates by trip purpose and time of day were obtained from a national travel survey in the Netherlands, and comparable data might not be available in the United States.

Computational Requirements:

Quovadis-BICYCLE can be run on a microcomputer on the MS-DOS platform and is currently being updated to run in a Windows 95 environment.

User Skill/Knowledge:

Some knowledge of travel demand modeling techniques is required.

Assumptions:

Bicycle trip generation rates are essentially assumed to be constant across zones, controlling for population and employment levels, and are based on current bicycle trip generation rates as determined from a national travel survey.

Facility Design Factors:

Since the model assigns trips based on the shortest travel time route, the model is capable of evaluating the impacts on the zone-to-zone distribution of trips and on the assignment of these trips to the network, as a result of new facilities or improvements to existing facilities which decrease travel time. Travel time on existing facilities can change if the type of facility changes, as long as different speeds have been specified according to facility type. Travel times can also change if measures are implemented to reduce bicyclist delay at intersections (delay reductions must be entered manually).

Conceivably, other factors which influence route choice could be included by assessing penalties to link speed or intersection delay, although this would require assumptions about the bicyclist's tradeoff between speed and other link attributes.

Output Types:

The output of the model includes forecast bicycle flows by facility/link. The number of existing and future bicyclists on each link can also be identified by time period and trip purpose.

The accessibility and safety modules of the model can further be used to:

- Calculate the extra distance (detour distance) bicyclists have to travel as compared to straight-line distance;
- Track and graph bicycle accidents;
- Assess whether bicycle paths are desirable from a safety point of view;
- Trace unsafe crossings (long-waiting times combined with number of bicyclists and number of accidents);
- Determine the effects on traffic safety and detour distance of adding a bicycle path.

Real-World Examples:

In addition to applications in the Netherlands, QUOVADIS-BICYCLE has been applied by Allott Transportation to Ipswich, UK. Modeled trip patterns were compared to actual trip patterns and to use of a conventional desktop and field study for identifying a bicycle network. While the model overpredicted bicycle flows, the particular routes identified as part of the bicycle network remained broadly the same. (Department of Transport, 1995).

Contacts/Source:

QUOVADIS-BICYCLE was developed in the Netherlands by DHV Environment and Infrastructure for the Dutch Ministry of Transport. Contact Dick Rooks, DHV Environment and Infrastructure, Laan 1914 No. 35, P.O. Box 1076, 3800 BB, AmersFoort, Netherlands.

Publications:

DHV Environment and Infrastructure. QUOVADIS-BICYCLE User's Manual. (no date)

Department of Transport. Traffic Advisory Leaflet 8/95: Traffic Models for Bicycling. London, UK, 1995.

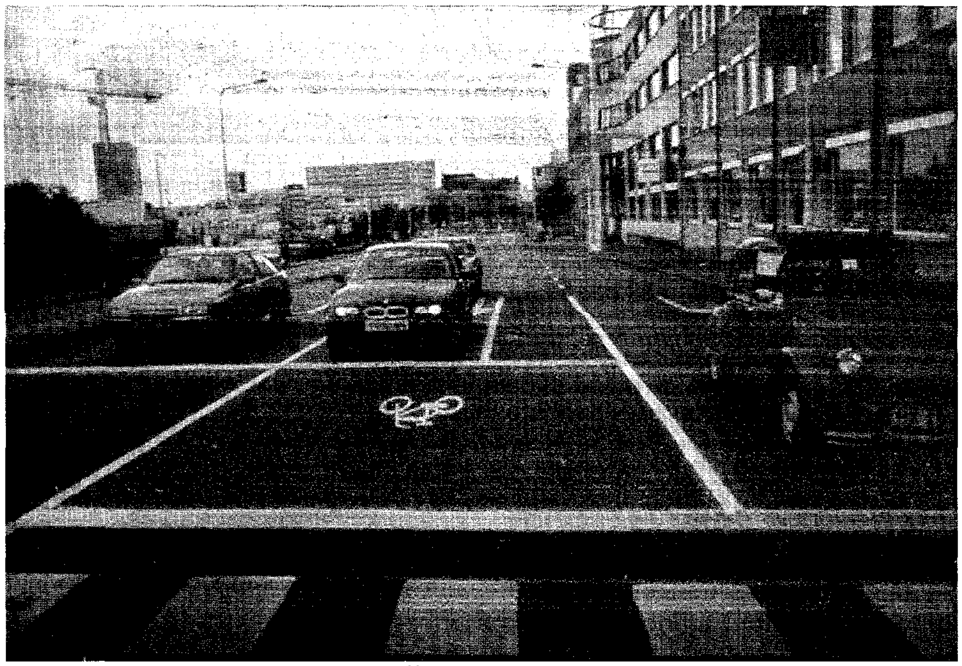

Figure 2.9 A bicycle box at a traffic signal in Groningen, Netherlands. The box allows bicyclists to wait in front of motor vehicles.

Evaluative Criteria: How Does It Work?

Performance:

See "Real-World Examples."

Use of Existing Resources:

This approach builds on existing travel modeling efforts, and primarily utilizes existing data on travel behavior that must be collected for these efforts. Collection of additional bicycle count data is required, as is modification of the road network to include bicycle facilities and characteristics. The resources required for network modification and conducting bicycle counts increase in proportion to the accuracy desired for modeling purposes.

Travel Demand *Model Integration:*

Quovadis-BICYCLE is structured like. a traditional travel demand model. It can import network and/or socioeconomic data from car models including Quovadis-CAR, Tranplan, TRIPS, and Proset. However, it is not fully integrated with network modeling for other modes; in particular, a mode choice component is lacking.

Applicability to Diverse Conditions:

Trip data and the network model must be developed specifically for the area being modeled. Once the model system is developed, proposed modifications to the local network can be tested.

Usage in Decision-Making:

No information available.

Ability to Incorporate Changes:

Trip data and the network model must be developed specifically for the area being modeled. Once the model system is developed, proposed modifications to the local network can be tested.

Ease-of-Use:

Not evaluated. The software can be run in an MS-DOS environment.

Comments:

This model bears many similarities to the TRIPS bicycle model (described in Section 2.10) in terms of its purpose and structure. Primary differences include the methods used to estimate the base bicycle trip table; the segmentation of trips by purpose and time of day in QUOVADIS; ability to incorporate link-specific travel speeds in TRIPS; the treatment of intersection delay in QUOVADIS; and the ability of QUOVADIS to track accident statistics and calculate accessibility and safety measures. However, TRIPS has advanced recently by integrating mode choice into the modeling process.

Demand Estimation:

2.10 Bicycle Travel Models: START and TRIPS

Categories:

• 4 Bicycle ☐ Pedestrian ☒ Facility-Level ☒ Area-Level

Authors and Development Dates:

MVA (1995)

Purpose:

MVA, a British consulting firm, has developed two separate models that include non-motorized travel:

1. START, a mode choice model that includes both bicycling and walking as options.

2. TRIPS, a network model package that includes a bicycle network option called MVCycle.

START is an incremental model that uses the best available representation of existing travel patterns (trips by origin/destination and mode), combined with changes in the time and monetary cost of travel to predict future travel patterns.

The zonal and network structure of the MVCycle network model is based on the TRIPS road and public transport models for the region. The primary purpose of the model is to distribute future bicycle trips given a network of existing and proposed roads and bicycle facilities, and to identify major points of conflict between potential bicycle flows and existing heavy traffic flows. The current version of the model does not predict overall bicycling volumes as a result of network improvements; rather, it evaluates the network distribution of trips under an assumed overall future level of bicycling.

Structure:

The representation of transport supply in the START mode choice model is not very detailed, on the order of 50 zones for a regional model (compared with several hundred for a typical travel model), so considerable attention is given to modeling intrazonal as well as interzonal movements. Bicycling and walking are currently considered by entering exogenously generated changes to travel time/cost. In addition, intrazonal demand is segmented into trips above and below walking distance.

Currently, zonal mode shares for each mode as determined from START can be used as inputs in developing trip tables for the TRIP model. Feedback from changes in bicycle costs based on changes in network characteristics from TRIPS can be performed manually, although costs from the TRIP model must be summarized in an aggregate format compatible with the START model zonal structure. In the future, linkages of bicycle costs are expected to be developed between the TRIPS network and the START model.

The development of the bicycle network model for TRIPS consists of the following steps:

1. Development of base-year and future-year networks of bicycle facilities.
2. Development of base-year bicycle trip tables.
3. Assignment of base-year bicycle trips to the bicycle network.
4. Re-estimation of bicycle trip tables based on actual roadway counts.
5. Factoring of base-year trip tables to develop future-year trip tables.
6. Assignment of future-year trips to the future-year bicycle network.

The approaches used for each step are described below. The network is evaluated separately under p.m.-peak hour and off-peak trip levels.

1. **Development of base-year and future-year networks of bicycle facilities. The bicycle** network is constructed using the TRIPS software package and is a modified version of the road network for the road traffic model. The network is set up to exclude motorways and to include bus lanes, pedestrian zones, off-road bicycle facilities, and other modifications as appropriate to describe the network likely to be used by cyclists. Different bicycle travel speeds are established for five different types of links (for example, 20 km/h for roads shared with motor vehicles and five km/h for walk links). Link speeds can also be modified on a link-specific basis for other factors which may affect travel speed, such as topography or frequent intersections. Also, the interaction between bicycling and public transport can be modeled by allowing carriage of bicycles on trains (i.e., including rail links in the bicycle network) and/or bicycle park-and-ride at rail stations.

3. **Development of base-year bicycle trip tables.** Base-year bicycle trip tables can be constructed through different methods. The method applied by the MVA to Leicester consists of the following steps:

   a. The car and public transit trip tables from the road and transit models were used to construct total person trip tables (bicycle and walk trip tables were not available from these models);

   b. A bicycle trip length distribution was developed from the local household travel survey, with trip times converted to distances using a sliding scale from 10 to 20 km/h (longer trips are assumed to be ridden by faster cyclists);

   c. The trip length distribution of motorized journeys was constructed, and total motorized trips were re-allocated among distance bands to so that the proportion of trips by distance band was the same as the actual proportion of bicycle trips by distance band.

d. Bicycle matrices were derived from the re-allocated motorized trip matrices based on the results of the home interview survey showing that bicycle trips were 2.62 percent of motorized trips.

3. **Assignment of base-year bicycle trips to the bicycle network.** Bicycle trips can be assigned to the network either by the least-cost method or by using a probability model driven by the difference in cost (travel time) between alternative paths and the least-cost path. The rationale for using the probability model, rather than a simple least-cost assignment, is to "better simulate the tendency of cyclists to use alternative routes to fast and / or busy roads." The effect of motor vehicle traffic congestion on cyclists can also be evaluated by assuming that link travel time for cyclists is increased by one-third of the increase in auto travel time caused by congestion. Finally, the model allows volume and speed of traffic on each link to be used to develop travel time penalties reflecting their disutility for cyclists, although this was not done for the Leicester model.

4. **Re-estimation of bicycle trip tables based on actual roadway counts.** The base-year assigned travel trips were compared with actual field counts of cyclists, and the bicycle trip matrices were modified so that assigned trips more closely matched actual counts.

5. **Factoring of base-year trip tables to develop future-year trip tables.** In the Leicester study, the base-year trip tables were factored under the assumption that in the forecast-year bicycling would represent 12 percent of all trips. The model is intended to represent a scenario "in which measures to encourage bicycling have substantially overcome the safety / qualitative obstacles to bicycling that exist today." It would also be possible to use results from the START model mode choice assignment, or from other sources, to estimate future bicycling levels for the purpose of factoring trip tables.

6. **Assignment of future-year trips to the future-year bicycle network.** The factored future-year trip tables are assigned to the future-year bicycle network. This step produces potential future flows on each network link, and can be used to identify major points of conflict between bicycle flows and existing heavy traffic flows.

Calibration/Validation Approach:

Calibration is performed using counts of actual bicycle traffic and standard mathematical calibration techniques.

Inputs/Data Needs:

The following data on travel patterns were used:

1. Auto and transit trip tables from the local road and transit models.
2. Census work-trip origin / destination data at the ward level.
3. Local home interview travel survey data.

In addition, counts of actual bicycle traffic were used for model calibration, A basic bicycle network can be constructed from the existing road network used for modeling purposes. Modification of this network requires some additional data collection on link characteristics relevant to cyclists.

Potential Data Sources:

See above.

Computational Requirements:

The model consists of proprietary software which can be run on a personal microcomputer.

User Skill/Knowledge:

A knowledge of travel modeling techniques is required.

Assumptions:

The model has not been used to forecast levels of bicycling as a result of network improvements. Instead, current bicycle trip distributions are increased by a uniform factor which represents an assumed future level of bicycling, under ideal conditions.

Facility Design Factors:

Network assignment is based on travel time, for which speeds can be varied by link. Therefore, the model is capable of evaluating the route choice (but not mode choice) impacts of modifications to an existing facility which increase travel speed, as well as the creation of a new facility. An example of the former might be construction of a bicycle-only facility parallel to a shared bicycle/pedestrian path, or elimination of traffic conflict points along a road with a bike path.

The model also contains relationships which factor the link travel time so as to represent the perceived effect of volume and speed of traffic on the attractiveness of each link to cyclists. This factoring involves subjective estimates of the tradeoffs assigned by cyclists to travel time vs. route factors (volume, speed). Link travel times could also conceivably be factored based on other link attributes such as pavement quality, environmental quality, etc. Development of such factors may benefit from the development of route choice models using stated-preference survey techniques, which can be used to quantitatively estimate tradeoffs between travel time and other factors.

Output Types:

The output of the START model includes forecast mode shares by zone. The output of the MVCycle model includes forecast p.m.-peak and off-peak bicycle flows by facility/link.

Figure 2.10 A bicycle lane that ends before an intersection.

Real- World Examples:

The bicycle model has been applied in Leicester, England (see MVA, 1995).

Contacts/Source:

MVA of Manchester, UK, has developed the TRIPS suite of programs for travel modeling, including START for travel demand forecasting and MVCYCLE for route choice for cyclists. Contact Rosemary Sharples at MVA, 26th Floor, Sunley Tower, Piccadilly Plaza, Manchester, Ml 4BT, United Kingdom.

Publications:

MVA, *Leicesfer Bicycle Model Study, Final Report,* prepared for Leicestershire County Council, Contract No. 02/C/1428, October 1995.

Evaluative Criteria: How Does It Work?

Performance:

No information is available.

Use of Existing Resources:

This approach builds on existing travel modeling efforts, and primarily utilizes existing data on travel behavior which must be collected for these efforts. Collection of additional bicycle count data is required, as is modification of the road network to include bicycle facilities and characteristics. The resources required for network modification and conducting bicycle counts increase in proportion to the accuracy desired for modeling purposes and the size of the network to be modeled.

Travel Demand Model Integration:

The START and TRIPS model structures for cyclists are based on the existing structures of these models for evaluating automobile and transit travel. START integrates bicycling into the mode choice model, although trip generation characteristics and changes in generalized travel cost for all modes must be developed exogenously. The bicycle network model in TRIPS uses both trip-making and network data from the auto and transit networks but as of yet does not feed generalized cost information from the bicycle network into trip generation or mode choice.

Applicability to Diverse Conditions:

Trip data and the network model must be developed specifically for the area being modeled. Once the model system is developed, proposed modifications to the local network can be tested.

Usage in Decision-Making:

Not evaluated.

Ability to Incorporate Changes:

Trip data and the network model must be developed specifically for the area being modeled. Once the model system is developed, proposed modifications to the local network can be tested.

Ease-of-Use:

Not evaluated. The latest version of TRIPS runs in a Windows environment.

Comments:

The following improvements have been proposed for future efforts:

1. Decreasing zone sizes for the bicycle network, and evaluating other methods of constructing trip matrices.

2. Incorporation of junction modeling to more accurately model traffic delay and evaluate the effects of bicycle priority measures at junctions.

3. Combining road traffic and bicycle assignments, i.e., assigning bicycle, auto, and transit trips simultaneously.

This model bears many similarities to the QUOVADIS bicycle model (described in section 2.9) in terms of its purpose and structure. Primary differences include the methods used to estimate the base bicycle trip table; the segmentation of trips by purpose and time of day in QUOVADIS; ability to incorporate link-specific travel speeds in TRIPS; the treatment of intersection delay in QUOVADIS; and the ability of QUOVADIS to track accident statistics and calculate accessibility and safety measures. However, TRIPS has advanced recently by integrating mode choice into the modeling process.

Demand Estimation:

2.11 Pedestrian Demand Models

Descriptive Criteria: What is It?

Categories:

☐ Bicycle ☒ Pedestrian ☒ Facility-Level ☒ Area-Level

Authors and Development Dates:

Haas and Morrall(l967); Ness, Morrall, and Hutchinson (1969); Kagan, Scott, and Avin (1978)

Purpose:

A handful of pedestrian demand models were developed in the 1960s and 1970s for forecasting pedestrian flows and prioritizing pedestrian improvements in CBD areas. These models were developed with a structure similar to standard transportation planning models, including zonal trip generation based on land use characteristics and trip distribution and assignment over a network based on a gravity model approach (see entry for “Regional Travel Models,” Method 2.8).

Kagan, Scott, and Avin (1978) outlined a formal Pedestrian Planning Process (PPP), including a demand modeling phase and a design and evaluation phase. The PPP was intended to help cities develop a network of pedestrian facilities, particularly in their downtown core area, which would “ensure and foster effective exchange for pedestrian trip-making between and within planned and existing activity centers.” The PPP includes a comprehensive evaluation of existing and forecast pedestrian travel patterns and movement requirements. The PPP can be used to predict changes in trip patterns as a result of pedestrian facility improvements or land uses and identify and prioritize actions for improvements to facilities.

At least two other studies in the 1970s sought to predict pedestrian volume in CBDs as a function of adjacent land uses and facility characteristics (e.g., sidewalk width) but did not include the development of a full pedestrian demand model based on a network of pedestrian facilities. These studies are discussed in the entry for “Pedestrian Sketch-Plan Methods,” Method 2.4 (Behnam and Patel, 1977; Pushkarev and Zupan, 1971).

Structure:

The PPP is based on methods and concepts similar to those found in the standard four-step urban transportation planning process. A detailed 27-step analysis process is outlined, including 13 steps in the demand modeling phase and 14 steps in the design and evaluation phase. Demand modeling is based on a ‘gravity model approach to show the distribution and assignment of pedestrian volumes over a network, under both current and forecast conditions. The primary components of the analysis include:

1. Trip generation characteristics, as a function of land use type.

2. Trip making propensity between land use activities, as a function of connecting pathway attributes.

3. The trip exchange patterns resulting from the above.

4. Assignment of these trips to alternative network pathways.

As in standard transportation planning, trip characteristics are analyzed separately by purpose and by time of day.

Calibration/Validation Approach:

The model is calibrated based on pedestrian counts, using standard calibration methods (see entry for "Regional Travel Models," Method 2.8).

Inputs/Data Needs:

The FHWA method requires the following input data:

- Base maps;
- Land use by type and size (existing and future), including vacant parcels;
- Transit usage;
- Parking by type and size;
- Transit portal locations; and
- Peak-hour pedestrian counts.

The following additional data are optional:

- Pedestrian survey results (trip characteristics including mode of arrival, time of arrival/departure, workplace location, midday trip purposes and destinations, attitudinal factors and concerns affecting route choice, etc.);
- Survey data to verify trip generation rates by land use type;
- Signal timing;
- Attribute scoring (i.e., the relative importance placed on various pedestrian design features); and
- Site-specific values for trip generation and attraction and for friction factors (see "Facility Design Factors" below).

Potential Data Sources:

The PPP manual includes representative values for trip generation by land use type (trips per square foot) and by time of day.

Computational Requirements:

The PPP was designed to be implemented using Urban Transportation Planning System (UTPS) software packages.

User Skill/Knowledge:

The procedure outlined is fairly complex but can be applied by anyone with a basic knowledge of standard four-step transportation planning procedures.

Facility Design Factors:

A fundamental element of the PPP is that network paths are described by an impedance or friction factor, which relate perceived distance to actual distance (time) along the path. Perceived distance can be a function of any number of factors, such as safety, comfort and amenities, visual interest, queues and congestion, vertical displacement, etc. These impedance factors must be developed based on site-specific surveys of facility characteristics and on assumptions about the impedances attached to various attributes, either from local pedestrian surveys or from other studies.

The PPP manual includes default impedance factors, as well as guidance for rating facilities, for the following attributes:

- Accessibility;
- Amenities;
- Attractiveness;
- Physical comfort;
- Psychological comfort;
- Information; and
- Safety.

It also includes adjustment factors for elevation changes (stairs, escalators, ramps), traffic crossings, and crowding.

Output Types:

The model predicts future flows on a pedestrian network, by link, under future land use and pedestrian network conditions.

Real- World Examples:

Hass and Morrall (1967) conducted a survey of pedestrian tunnels between all major buildings and parking lots of Carleton University in Ottawa, Canada. The objective was to develop a pedestrian demand model for future design criteria. Data were collected using an O-D questionnaire survey, and the model was calibrated using screen-line counts and walking time-distance surveys. Trips were assigned to a network system by a

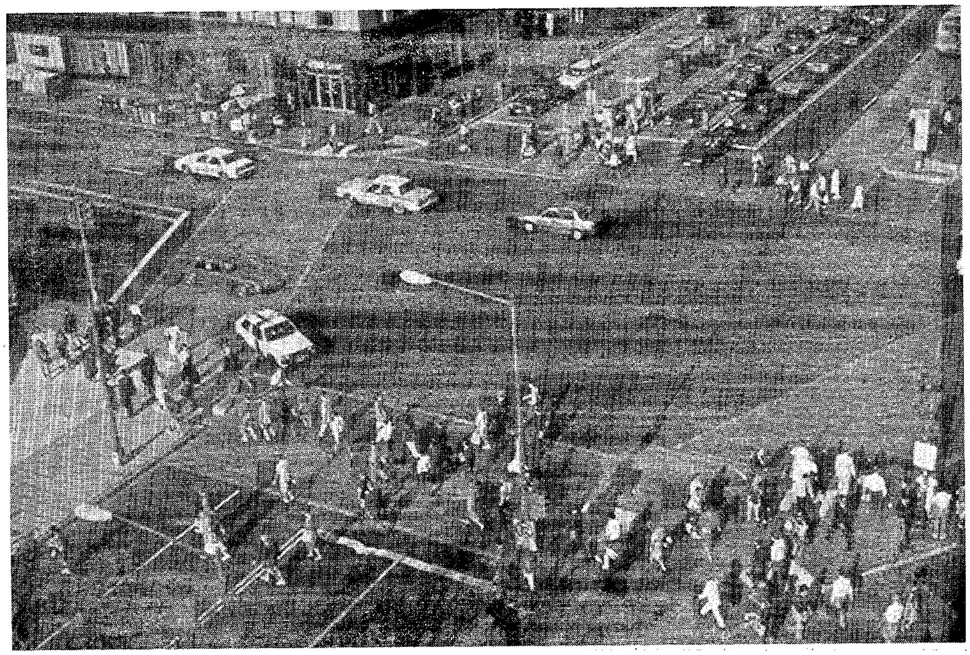

Figure 2.11 The Pedestrian Planning Process manual includes values for trip generation by land use type and by time of day.

computer assignment program based on results of the survey. (Referenced in Behnam and Patel, 1977.)

Ness, *Morrall,* and *Hutchinson (1969)* applied the gravity model technique to forecast pedestrian volume in the Toronto area. The CBD was divided into office zones, and pedestrian links were coded depending on street configuration and the locations of the centroids of these zones. Trip generation and attraction rates were measured for office zones and transportation terminals and were used in conjunction with a set of friction factors and minimum-path walking trees as inputs to the gravity-type distribution model. The minimum path was calibrated on the basis of walking time, waiting time at intersections, street attractiveness, and a turn penalty. (Referenced in Behnam and Patel, 1977.)

Contacts/Source:

Jeffrey Zupan: Regional Plan Association of New York (New York, NY)

Publications:

Behnam, Jahanbakhsh and Bharat G. Patel, *A Method for Estimating Pedestrian Volume in a Central* Business *District,* Pedestrian Controls, Bicycle Facilities, Driver Research, and System Safety, Transportation Research Record 629, Washington, DC, 1977.

Hass, R.C.G. and J.F. Morrall. *Circulation Through* a Tunnel *Network.* Traffic Quarterly, April 1967.

Kagan, L.S., W.G. Scott, and U.P. Avin *(1978). A Pedestrian Planning Procedures Manual.* Prepared for the Federal Highway Administration, Report Nos. FHWA-RD-79-45, FHWA-RD-79-46, and FHWA-RD-79-47 (3 volumes).

Ness, M.P., J.F. Morrall, and B.G. Hutchinson. *An Analysis of Central Business District Pedestrian Circulation Patterns.* Highway Research Record 283, 1969.

Pushkarev, Boris, and Jeffrey M. Zupan. *Pedestrian Travel Demand.* Highway Research Record 355, 1971.

Evaluative Criteria: How Does It Work?

Performance:

No information is available.

Use of Existing Resources:

This method generally requires local data collection on pedestrian flows, network characteristics, land uses, and other trip generators, as well as the development of a network model using standard transportation planning software.

Travel Demand Model Integration:

This method is based on the same methodology used for regional travel demand models and can be implemented with standard travel modeling software. However, it requires the development of an area-specific model at the pedestrian scale, including a pedestrian network, zonal structure, and related data files.

Applicability to Diverse Conditions:

This method is primarily applicable to an urban CBD or other activity center with significant pedestrian activity.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

Once a model is developed, a wide variety of facility improvements can be analyzed.

Ease-of-Use:

Development of a model and appropriate data and parameters would require a significant level of effort.

Relative Demand Potential:

2.12 Market Analysis

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☐ Pedestrian ☐ Facility-Level ☒ Area-Level

Authors and Development Dates:

Ohrn (1976); Deakin (1985); Erickson (1992); Clark (1997)

Purpose:

This is a general type of approach which estimates the maximum potential number of trips by bicycle or walking, based on: (1) current trip length distributions, usually by trip purpose; (2) rules of thumb on the maximum percentage of bicycling or walking trips by trip distance and purpose; or (3) the percentage of the population likely to switch to bicycling or walking, based on the definition of a target market of bicyclists or walkers according to commute distance, demographic characteristics, etc. An ideal network of facilities is assumed — i.e., this method estimates how many trips might take place if quality of facilities was not an issue.

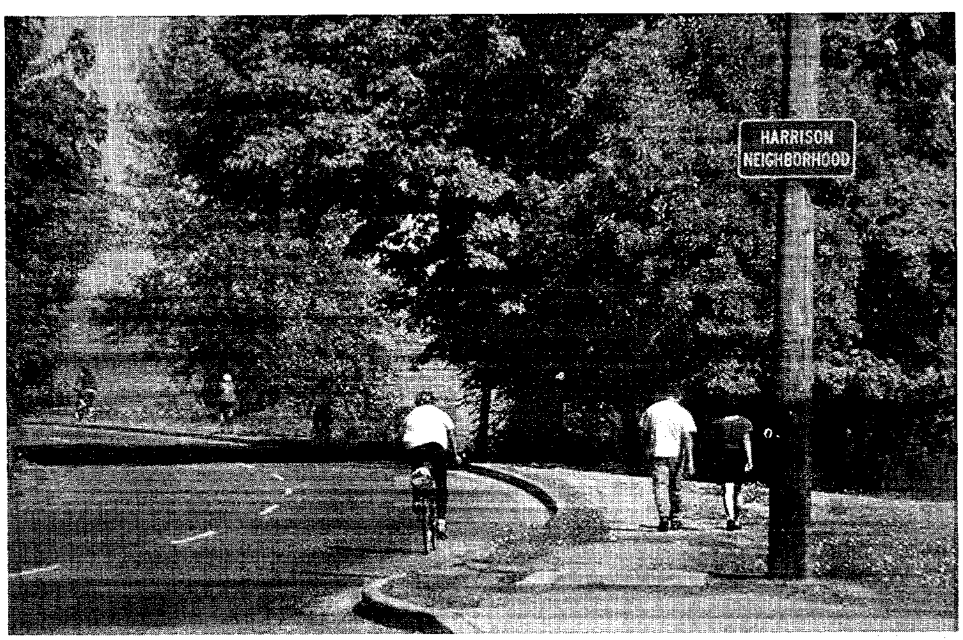

Figure 2.12 A market analysis approach can be used to estimate the maximum potential number of bicycling and walking trips in an area.

Structure:

Ohrn (1976) applied the following steps to estimate the potential for bicycle trips in the Minneapolis-St. Paul area:

1. Assume that the maximum length of a bicycle trip is 3.2 km.

2. Compute the total number of home-based trips by trip purpose that are less than two miles long, based on household travel survey data.

3. Apply assumptions about the percentage of these trips-by-trip type which can be made by bicycle (ranges from 5 percent for medical to 50 percent for school trips) to estimate the total trips attracted to bicycle if proper facilities were provided.

Deakin (1985) defined a demographic target group for San Francisco Bay Area commuter bicycling, based on data from the Bay Area Travel Survey, a review of the literature, and interviews with local and State officials. Her market was defined as: employed full-time; under 40 years old; travels less than 11.2 km one-way to work; drives alone during the peak-period; and owns a bike suitable for commuting. She then used these criteria to estimate a reasonable upper bound on the size of the potential bicycle commuter market.

Erickson *(1992)* refined Deakin's approach and applied it to the Chicago area. He developed trip length distributions by county for work trips less than 9.6 km, based on the 1980 Urban Transportation Planning Package. He then defined a target market population similar to Deakin's. Given information on the size of this target market population, he developed lower-bound and upper-bound estimates for the near-term mode shift potential, using statistics about the percentage of adults who bicycle regularly and the percentage of current bicycle commuters (derived from national studies), multiplied by the size of the target market.

Clark (1997) described a process to adjust vehicle trip tables in a travel demand model to account for future increases in bicycle and pedestrian trips. Existing trips are stratified by length and purpose, and adjustment factors which represent a potential percent increase in bicycle and pedestrian trips as a result of future improvements are applied to reduce the number of vehicle trips between each origin-destination pair. The adjustment factors vary by trip purpose (home-based work, home-based other, and non-home-based); length (less than 0.8 km, 0.8 to 4.0 km, and 4.0 to 8.1 km); and mode (pedestrian and bicycling), and are based on local judgment.

Calibration/Validation Approach:

Validation of this method would require observations of areas which already have a complete network of bicycle facilities. While a few such areas may exist, they have not (to our knowledge) been studied with the particular aim of determining if the entire market potential has been reached.

Inputs/Data Needs:

1. This method at a minimum requires local data on trip lengths by trip purpose, which can usually be obtained from household travel surveys.

2. Some variations of the method require assumptions about the total number of trips (by trip distance, purpose, and/or personal characteristics), which can be converted to bicycling or walking.

3. Some variations on this method also require other data to estimate the size of the target market population, which may be obtained from household surveys, census, and other data depending on how the target market is defined.

Potential Data Sources:

Estimates of market diversion potential could potentially be obtained from surveys of potential bicyclists and pedestrians (see entry for "Preference Surveys"). In practice, they have been developed based on the professional judgment of planners and analysts.

Computational Requirements:

This type of analysis can generally be performed using a spreadsheet, although statistical software may be required for analyzing household travel surveys or other data sources.

User Skill/Knowledge:

In general, no special skills are required to apply this method.

Assumptions:

The most significant assumption employed in this method is in estimating the total mode shift by trip type, trip distance, market segment, etc., under the assumption of an ideal network of facilities. The methods documented here assume that (1) a certain percentage, if not all, of the target market will switch modes; or (2) a given percentage of trips by type and distance will be converted to bicycle or walk trips. These factors have generally been developed based on judgment and speculation. In fairness, little concrete evidence is available given the absence of areas with well-developed bicycle networks. The methods also generally ignore the potential effects of many other factors, such as quality of competing modes, terrain, weather, and public attitudes.

Facility Design Factors:

The methods assume a network of ideal facilities. However, they do not address which design factors are needed to create an ideal facility/network.

Output Types:

The output of this method may be the total number or percent of bicycle or walk trips estimated in the future under ideal conditions. The results can also be applied (with further assumptions) to estimate the corresponding reduction in automobile and/or transit trips. However, the method is only capable of treating utilitarian, not recreational, trips.

Real- World Examples:

A basic example of this approach can be found in Ohrn (1976) and is also outlined in Northwestern University Traffic Institute (no date). The approach was also applied by Clark (1997) using origin-destination trip tables from travel models. Deakin (1985; referenced in FHWA Case Study # 1) estimated a demographic target market and a probable upper bound on those likely to switch to bicycling, based on household travel survey data. Erickson (1991; also referenced in FHWA Case Study # 1) attempted to refine Deakin's approach and apply it to northeastern Illinois. Other variations on the market analysis method are referenced in the literature cited here.

Contacts/Source:

David Clark: Kittelson and Associates (Portland, OR).

Publications:

Clark, David E., P.E., *Estimating Future Bicycle and Pedestrian Trips From A Travel Demand Forecasting Model,* Institute of Transportation Engineers, 67th Annual Meeting, 1997.

Deakin, Elizabeth A. *Utilitarian Bicycling: A Case Study of the Bay Area and Assessment of the Market for* Commute *Bicycling.* University of California, Berkeley, ITS Research Report (1985). (Referenced in FHWA Case Study #1).

Erickson, Michael. *The Potential for Bicycle Transportation in Chicagoland.* Proceedings of the Velo 1992 conference (Perspectives Mondiales Sur le Velo; The Bicycle: Global Perspectives). (Erickson's work is also documented in his master's thesis from Northeastern Illinois University (1991) and referenced in FHWA Case Study # 1.)

Federal Highway Administration (Stewart A. Goldsmith). Case Study No. 1: *Reasons Why Bicycling and Walking Are Not Being Used More Extensively As Travel Modes.* National Bicycling and Walking Study, U.S. Department of Transportation (FHWA), Publication No. FHWA-PD-92-041.

Louisse, Cees J. *Obstacles and Potentions (sic) for Replacing Car Trips by Bicycle Trips.* Proceeds of the Velo 1992 conference (Perspectives Mondiales Sur le Velo; The Bicycle: Global Perspectives), 1992.

Northwestern University Traffic Institute. *Pedestrian and Bicycle Considerations in Urban Areas -An Overview.* Training course developed for the U.S. Department of Transportation, Federal Highway Administration, in cooperation with Barton-Aschman Associates. (no date; est. late 1970s).

Ohrn, Carl E. *Predicting the Type and Volume of Purposeful Bicycle Trips.* Transportation Research Record No. 570, 1976.

Evaluative Criteria: How Does It Work?

Performance:

No information is available.

Use of Existing Resources:

The method can largely be applied using existing data, although the less data collected, the greater the number of assumptions made.

Travel Demand Model Integration:

The method is not designed to be integrated with travel demand models, although it may utilize travel demand model output in the form of trip tables by mode and purpose.

Applicability to Diverse Conditions:

The basic methodology can be applied in different areas.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

The method can easily be used to test changes in assumptions about the potential market diversion by trip purpose, distance, and market segment. However, the method is a rough approximation of total mode split and is not sensitive to changes in facilities or policies (the effects of these must be estimated manually by adjusting the potential market diversion factors).

Ease-of-Use:

The method is relatively easy to apply assuming that the required data sources are available, although some analysis is required.

Relative Demand Potential:

■ 2.13 Latent Demand Score

Descriptive Criteria: What is It?

Categories:

❑ Bicycle ☐ Pedestrian ☒ Facility-Level ☐ Area-Level

Authors and Development Dates:

Landis (1996)

Purpose:

The Latent Demand Score (LDS) method, developed by Bruce Landis, provides a way to estimate the latent or potential demand for bicycle travel, i.e., the level of travel that would occur if a bicycle-facility existed on a road segment. The LDS method may be combined with supply-side facility analysis methods, such as bicycle level of service measures, to indicate facilities with the greatest need for improvement.

Structure:

The method analyzes the proximity and trip generation potential of activity centers to determine the potential demand for the facility. Activity center potential is analyzed using probabilistic gravity model techniques.

The LDS model involves the following steps:

1. Estimate the percentage of trips taken by bicycle by area residents for home-based work, home-based shopping, home-based recreational/social, and home-based school trips.

2. Using a geographic information system (GIS), geocode the locations of activity centers near the proposed facility.

3. Establish the Tripmaking Probability Summation (TPS) (see "Assumptions").

4. Validate the Demand Indicator Values (DIVs).

5. Multiply the DIVs with its trip generation for each activity center using the ITE Trip Generation manual.

6. Add the DIVs to calculate the segment's Latent Demand Score.

Calibration/Validation Approach:

Public participation and analyses on the conditions of the current roadway systems can be used to validate and justify the LDS results.

Inputs/Data Needs:

The LDS model requires the following data items:

- Home-based work trip markets (refer to "Assumptions" entry for methodology);
- Commercial employment by traffic analysis zone (TAZ);
- Public parks (categorized); and
- Elementary and middle school student population within each TAZ.

The model also uses the ITE Trip Generation manual.

Computational Requirements:

Uses spreadsheets and GIS.

User Skill/Knowledge:

Users should be familiar with probabilistic gravity models and should know how to operate a GIS.

Assumptions:

To establish potential home-based work markets for bicycle travel, census tracts were categorized by the number of home-based work trips with durations of less than 10 minutes. Autos were assumed to travel at an average of 48 km/h, so the distances involved total less than 8 km.

The LDS model assumptions are described below. To determine the TPS as stated in step 3, it is necessary to perform the following calculations:

- Calibrate the impedance factors (probability vs. distance) for each trip purpose;
- Multiply the indicators by their distance impedance; and
- Sum the value for the segment for each trip purpose.

Facility Design Factors:

The LDS only considers the demand-side for potential bicycle facilities and does not take into consideration the current road conditions. Nevertheless, Landis has developed a supply-side method called the Interaction Hazard Score or IHS Model that would complement the LDS results.

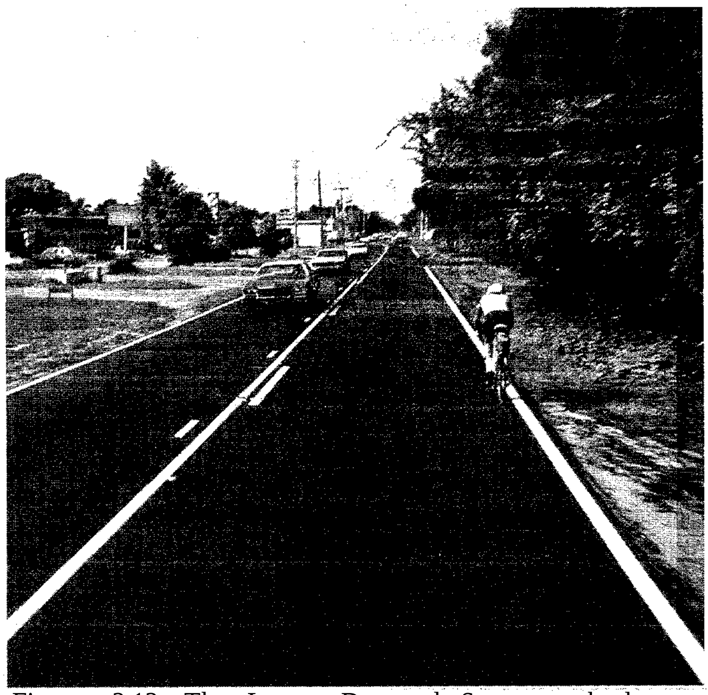

Figure 2.13 The Latent Demand Score method provides a way to estimate the level of travel that would occur if a bicycle facility (such as a paved shoulder or bicycle lane) existed.

Output Types:

The output consists of road segments ranked according to their latent travel demand. Road segments with high latent demand would have the highest priority for future funding. When using supply-side analyses such as level-of-service measures along with the LDS, the highest priority road segments are those with low levels of service and high-potential demand.

Real-World Examples:

Three localities in Florida are using the Latent Demand Model along with bicycle level-of-service models. The city of Tampa uses the methods to prioritize funding for new bicycle facilities while Hillsborough County uses the methods to prioritize improvements to existing bicycle facilities. The city of Birmingham, Alabama, incorporated the Latent Demand Model results involving facility prioritizations into their Bicycle, Pedestrian, and

Greenway Plan. The Latent Demand Model has also been tested recently in Philadelphia, PA.

Contacts/Source:

Bruce Landis, Sprinkle Consulting Engineers (Tampa, Florida).

Publications:

Landis, Bruce, and Jennifer Toole. *Using the Latent Demand Score Model to Estimate Use,* Forecasting the Future, Pro Bike/Pro Walk 96, Bicycle Federation of America — Pedestrian Federation of America, September 1996.

Evaluative Criteria: How Does It Work?

Performance:

Since the LDS only addresses the potential demand on improved road facilities, it works best when accompanied by a mechanism that addresses the current road conditions.

Use of Existing Resources:

Some data used in the model can be readily obtained from sources such as the census. Other data (e.g., the types and locations of activity centers) may need to be collected locally.

Travel Demand Model Integration:

The model is not intended to be integrated into regional travel models.

Applicability to Diverse Conditions:

It is possible to change the impedance factors to account for different local conditions. For example, the city of Birmingham added an impedance variable to account for mountainous terrain. To adjust for different travel patterns, they stratified the distance impedance variable into three groups: rural, suburban and urban.

Usage in Decision-Making:

The LDS is used primarily to prioritize the expenditures for existing and proposed bicycle facilities.

Ability to Incorporate Changes:

Since the calculations are performed using spreadsheets, input variables can be changed with ease.

Ease-of-Use:

Since the model uses software that is familiar to most professionals (i.e., spreadsheets and GIS), it is relatively simple to operate. Nevertheless, it is necessary to understand how to apply the modeling technique to the localized environment because each jurisdiction will have to customize it to meet its needs.

Comments:

Jennifer Toole (jtoole@rbagroup.com) stated in an e-mail the following advantages and disadvantages of the model:

Advantages: "It is a gravity model, and our clients have appreciated its similarity to other travel demand models. Also, we have been able to use it to shore up political support for bicycle facility construction. Most importantly for master planning projects, the model has enabled us to make informed decisions about appropriate priorities -- decisions that are based less on anecdotal evidence and more on objective input."

Disadvantages: "The model doesn't define potential ridership -- rather, relative demand compared to other segments of the route system."

Relative Demand Potential:

2.14 Pedestrian Potential and Deficiency Indices

Descriptive Criteria: What is It?

Categories:

☐ Bicycle • ZJ Pedestrian ☐ Facility-Level ☒ Area-Level

Authors and Development Dates:

City of Portland (1994)

Purpose:

The city of Portland, OR has developed two indices to help prioritize proposed pedestrian projects: the Pedestrian Potential Index and the Deficiency Index. The Pedestrian Potential Index identifies locations with high potential for pedestrian trip-making. The Deficiency Index identifies areas in which the quality of existing pedestrian facilities is low. The two indices are used in combination to identify projects in areas of high-demand potential and with significant existing deficiencies.

Structure:

Pedestrian Potential Index – The Pedestrian Potential Index uses three main factors:

1. Policy factors that deem certain areas (i.e., urban activity centers) as critical for pedestrians.

2. Proximity factors that identify whether the segment is close to pedestrian generators such as schools, parks, transit, or neighborhood shopping.

3. Pedestrian potential factors that describe the likelihood of walking based on five environmental factors, namely, mixed use/density, proximity to destinations, street connectivity and continuity characteristics, average parcel size, and slope. The factors were developed as described under "Calibration/Validation Approach."

A geographic information system (GIS) using MapInfo was developed to help visualize and analyze the three factors. Street segments were assigned a point value depending on if they qualify as critical pedestrian corridors, are pedestrian generators or have high-pedestrian volumes.

Deficiency Index – The Deficiency Index uses surrogates for ease of street crossing (e.g., traffic speed, traffic volumes, and roadway width), sidewalk continuity (i.e., sidewalk inventory data), and street connectivity (i.e., street segment length). These factors were based in part on factors established by 1,000 Friends of Oregon (1993) in developing Pedestrian Environment Factors (PEFs) for the region. Pedestrian accident locations also are considered. Like the Pedestrian Potential Factor, the Deficiency Index tabulates the factors separately then combines the points, and illustrates the high-, medium-, and low-deficient areas using GIS.

Calibration/Validation Approach:

To identify pedestrian factors for the Pedestrian Potential Index, Portland Metro developed a model using trips of two miles or less that were taken from the 1994 regional household travel survey and then geocoded by address. Using the Metro Regional Land Information System (RLIS) model, variables were developed such as intersection density per acre, average parcel size, slope, number of households and employment within one-half mile of each activity center. The travel data and variables were used to, construct a binomial logit equation that showed the likelihood of walking for a given trip. The variables that were chosen for the Pedestrian Potential Index were well correlated with pedestrian demand.

Inputs/Data Needs:

Pedestrian *Potential Index:* The following data are used for developing this index:

- Metro Regional Land Information System (RLIS) – data on intersection density per acre, average parcel size, slope, number of households and employment within 0.8 km from each activity center.'
- Locations of activity centers such as schools and parks.
- GIS data describing the street network.

Deficiency *Index:* Sidewalk inventory data, traffic speed, traffic volume, roadway width, length of the street segment, and pedestrian crash locations are used for developing this index.

Potential Data Sources:

Not applicable.

Computational Requirements:

The method uses a GIS. The software package MapInfo was used; other GIS packages could also be used.

User Skill/Knowledge:

A user should be proficient in GIS because the method uses spatial analysis tools to determine the highest potential and most deficient areas.

Assumptions:

It is assumed that the potential pedestrian activity in the area can be adequately indicated using the available land use and activity variables.

Facility Design Factors:

The method uses two indices to account for facility design factors: Pedestrian Potential Index and Deficiency Index. The factors considered in each are listed under "Inputs/Data Needs."

Figure 2.14 The Deficiency Index identifies areas in which the quality of existing pedestrian facilities is low.

Output Types:

The output consists of points according to street segment and factor, which are combined into two separate groups to formulate the Pedestrian Potential Index and the Deficiency Index. The street segments are classified by color in the GIS to illustrate the pedestrian potential or the deficiencies of the physical environment. The priority projects for future funding would be projects that rank high for both indices.

Real- World Examples:

The city of Portland, OR analyzed 91 projects that were classified as Pedestrian Districts, Main Street and Pedestrian Corridor projects. Each project received a Pedestrian Potential score and a Deficiency score that combined the street segment index points that were within the projects' boundaries.

The final proposed projects were prioritized using the Potential and Deficiency Index rankings, community input, and cost-effectiveness evaluations.

Contacts/Source:

Ellen Vanderslice, City of Portland, OR, Office of Transportation, Transportation Engineering and Development, 1120 SW 5th Avenue, Room 802, Portland, OR 97204.

Publications:

City of Portland, OR, Office of Transportation. *Identifying Priorities for Pedestrian* Transportation *Improvements*. Pedestrian Master Plan Project Development: Final Report, June 1997.

Evaluative Criteria: How Does It Work?

Performance:

The method provides two different ways to calculate the potential benefits of proposed pedestrian facilities. The first approach highlights the high-potential pedestrian areas that tend to have a functioning pedestrian environment while the second method focuses on functionally deficient areas where pedestrian activity is less likely to occur. These two indices were developed in recognition that there are two philosophies about how to spend pedestrian monies: improving high-pedestrian potential areas or improving areas of high deficiencies.

Use of Existing Resources:

The method uses an existing travel survey as well as land use information.

Travel Demand Model Integration:

The method was not designed for model integration.

Applicability to Diverse Conditions:

Variations of the indices could potentially be applied in other areas, based on local data availability. However, not all metropolitan areas will have land use data at the level of detail used in these specific indices.

Usage in Decision-Making:

The method was developed to help prioritize proposed pedestrian projects in the city of Portland's Pedestrian Master Plan. Neighborhood support and cost-effectiveness evaluations also were used. For the most part, projects that scored high for Pedestrian Potential scored low for Pedestrian Deficiencies, indicating that areas with high potential had already been developed for the most part with a functioning pedestrian environment. Nevertheless, the indices were still viewed as useful for helping prioritize projects.

Ability to Incorporate Changes:

The inputs can be easily revised in the GIS.

Ease-of-Use:

The use of GIS allows the user to easily understand the inputs and their effects on the final output.

Supply Quality Analysis:

2.15 Bicycle Compatibility Measures

Descriptive Criteria: What is It?

Categories:

• J Bicycle ☐ Pedestrian ☒ Facility-Level ☐ Area-Level

Authors and Development Dates:

Mozer (1994); Sorton and Walsh (1994); Dixon (1995); Federal Highway Administration *(1998)*

Purpose:

Bicycle compatibility measures, including stress-level and level-of-service indicators, measure the suitability of roadways for bicycle travel. These methods describe current bicycling conditions rather than forecasting potential demand. The measures combine factors such as motor vehicle traffic volume and speeds, lane width, and pavement quality into an index of overall suitability for travel.

Sorton and Walsh (1994) developed a method to determine the "stress level" for bicyclists as a function of roadway characteristics. The authors used three primary traffic variables in relation to different bicyclist skill levels. The primary traffic variables were peak-hour volume, curb-lane speed and curb-lane width; the bicyclist categories included child, youth, casual and experienced, although the authors do not recommend using the "child" category in analyses.

Mozer (1994) developed an LOS measure referred to as "Pedestrian, Bicycle, Auto, Transit Level of Access" (P-BAT LOA). The purpose was to establish a multimodal level of service measure as an alternative to traditional LOS measures, which do not consider bicycle, pedestrian or transit modes.

The Federal Highway Administration (1998) developed a bicycle compatibility index (BCI) to describe the compatibility of a facility for bicycling. The BCI uses a formula based on traffic volume, speed, lane width, and other indicators of bicyclist stress to rank a road segment for compatibility for bicycling, which is then equated to a level of service (LOS) rating. The BCI was developed for mid-block locations that exclude intersections to help planners evaluate the quality of existing facilities. Qualitative adjustment factors were developed to consider instances of high volumes of trucks or buses, right-turning vehicles and vehicles turning into and out of driveways. The BCI is intended to be used for operational evaluation, design, and planning. The BCI is partially based on the bicycle level of service measures developed by Sorton and Walsh (1994) and Mozer (1994), as described above.

Structure:

Sorton/Walsh: The following three-step process was developed to determine bicycle stress levels.

1. Select significant roadway variables that affect bicycle use.

2. Evaluate all street segments for bicycle use pertaining to these variables.

3. Analyze and rank the improvements needed for each street segment addressing the cost, political feasibility, and type of upgrade needed. Improvements should be selected after comparing the overall average stress level with the bicyclist type.

The following secondary variables were used to compare the bicycle compatibility of candidate streets:

- The number of commercial driveways per mile;
- Parking turnover; and
- The percentage of heavy vehicles such as trucks, buses, and recreational vehicles.

Note that the procedure should identify corridors or streets that have the highest potential for bicycle travel.

Mozer: To determine the level-of-access of street segments for bicycle use, this method uses three primary factors: outside-lane width, outside-lane speeds, and outside-lane volume, and four secondary factors: quantity of bicycle traffic using a width-bicycle volume factor, volume of heavy vehicle traffic, outside-lane penetrations, and on-street parking.

FHWA: For the development of the BCI, eight independent variables related to bicyclists' comfort levels were selected along with three variables that should be considered as an adjustment factor. These variables were combined to develop the BCI as follows:

BCI Model, Variable Definition and Adjustment Factors

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL	Presence of bicycle lane or paved shoulder (no = 0; yes = 1)
BLW	Bicycle-lane (or paved shoulder) width (meters to the nearest tenth)
CLW	Curb-lane width (meters to the nearest tenth)
CLV	Curb-lane volume (vehicles per hour in one direction)
OLV	Other lane(s) volume – same direction (vehicles per hour)
SPD	85th percentile speed of traffic (km/h)
PKG	Presence of a parking lane with more than 30 percent occupancy (no = 0; yes = 1)
AREA	Type of roadside development (residential = 1; other type = 0)
AF	f(t) + f(p) + f(rt) (adjustment factors for large truck volumes, on-street parking turnover, and volume of right-turning vehicles, respectively)

The BCI is then converted into a level of service measure on a scale of A through F, where A represents "extremely high" compatibility and F represents "extremely low" compatibility.

Calibration/Validation Approach:

Sorton/Walsh: The city of Madison, WI conducted a survey to validate the bicycle stress level for city streets. The primary variables (i.e., motor vehicle peak-hour volumes, curb-lane speed and curb-lane width) were studied using videotaping of selected road segments. Sixty-one survey participants were asked demographic questions and then rated specific primary variables using the video clips for each road segment. The proposed stress levels for each primary variable were then adjusted to reflect the participants' responses.

Mozer: No calibration or validation approach was mentioned.

FHWA: The BCI was validated using a video methodology that is similar to Sorton and Walsh but using a more comprehensive approach. The video survey interviewed 202 participants in Olympia, WA; Austin, TX; and Chapel Hill, NC. The participants were asked to rank their comfort level as bicyclists considering traffic volume, speed, and width for a variety of videotaped locations.

Inputs/Data Needs:

Sorton/Walsh: The three primary inputs include motor vehicle volumes, motor vehicle speed, and curb-lane widths.

Mozer: Like Sorton/Walsh, the three primary inputs include outside-lane volumes, outside-lane speeds, and outside-lane widths.

FHWA: The analysis uses the following inputs to create the BCI: bicycle-lane width, curb-lane width, curb- and other-lane volumes, motor vehicle speeds, type of roadside development, large truck volumes, motor vehicle parking turnover, and right-turn volume.

Potential Data Sources:

Sorton/Walsh: In addition, the following secondary variables could be used to compare the bicycle compatibility of candidate streets: the number of commercial driveways per mile; parking turnover; and the percentage of heavy vehicles such as trucks, buses, and recreational vehicles.

Mozer: The following secondary variables are used: quantity of bicycle traffic (per width of outside lane), volume of heavy vehicle traffic (using the same percentage by road segment as Sorton/Walsh), outside-lane penetration (based on number of turning movements), and on-street parking turnover.

FHWA: Some data required for the index may exist in local or state facility inventories or may already have been collected for local traffic impact studies. Additional field data collection may be required.

Computational Requirements:

Minimal computational requirements are needed.

User Skill/Knowledge:

An understanding of standard traffic data sources and collection methodologies is required.

Assumptions:

In general, this type of method assumes that the compatibility of the facility is adequately described by the specified factors. In practice, different individuals will assign different levels of importance to each of the factors. Also, this method only describes continuous mid-block segments and does not describe the overall compatibility of a route that includes intersections as well as segments with different characteristics.

Sorton/Walsh and *Mozer:* The authors assume that bicyclists want to reduce their mental stress so they will choose streets with lower volumes, speeds, and curb-lane widths. Bicyclists with different skill levels will vary in their desire to minimize their stress level. The proposed stress-level rating of one through five reflects this since each level has different interpretations of acceptability for different types of users.

Facility Design Factors:

Sorton/Walsh: This method focuses on the facility design using volume, speed, and curb-lane width as the primary variables. The secondary variables are the number of commercial driveways per mile, parking turnover, and the percentage of heavy vehicles.

Mozer: This method uses the same primary factors as Sorton/Walsh. The secondary variables differ yet still focus on the physical environment, such as the quantity of bicycle traffic, vehicle turning movements, heavy vehicle volumes, and on-street parking.

FHWA: The method uses the same facility design factors as Sorton/ Walsh but also includes the presence of bicycle lanes. The secondary variables include the number of driveways, parking turnover, percentage of heavy vehicles, and number of right-turning vehicles.

Output Types:

Sorton/Walsh: Each primary factor (motor vehicle volume, lane width, and traffic speed) is rated with a stress level of one to five. These are averaged to produce an overall stress level.

Mozer: Like the Sorton/Walsh method, each primary factor is rated with a stress level, and these factors are averaged.

FHWA: Each roadway segment receives a numeric BCI score, which is then converted to an A through F level-of-service measure.

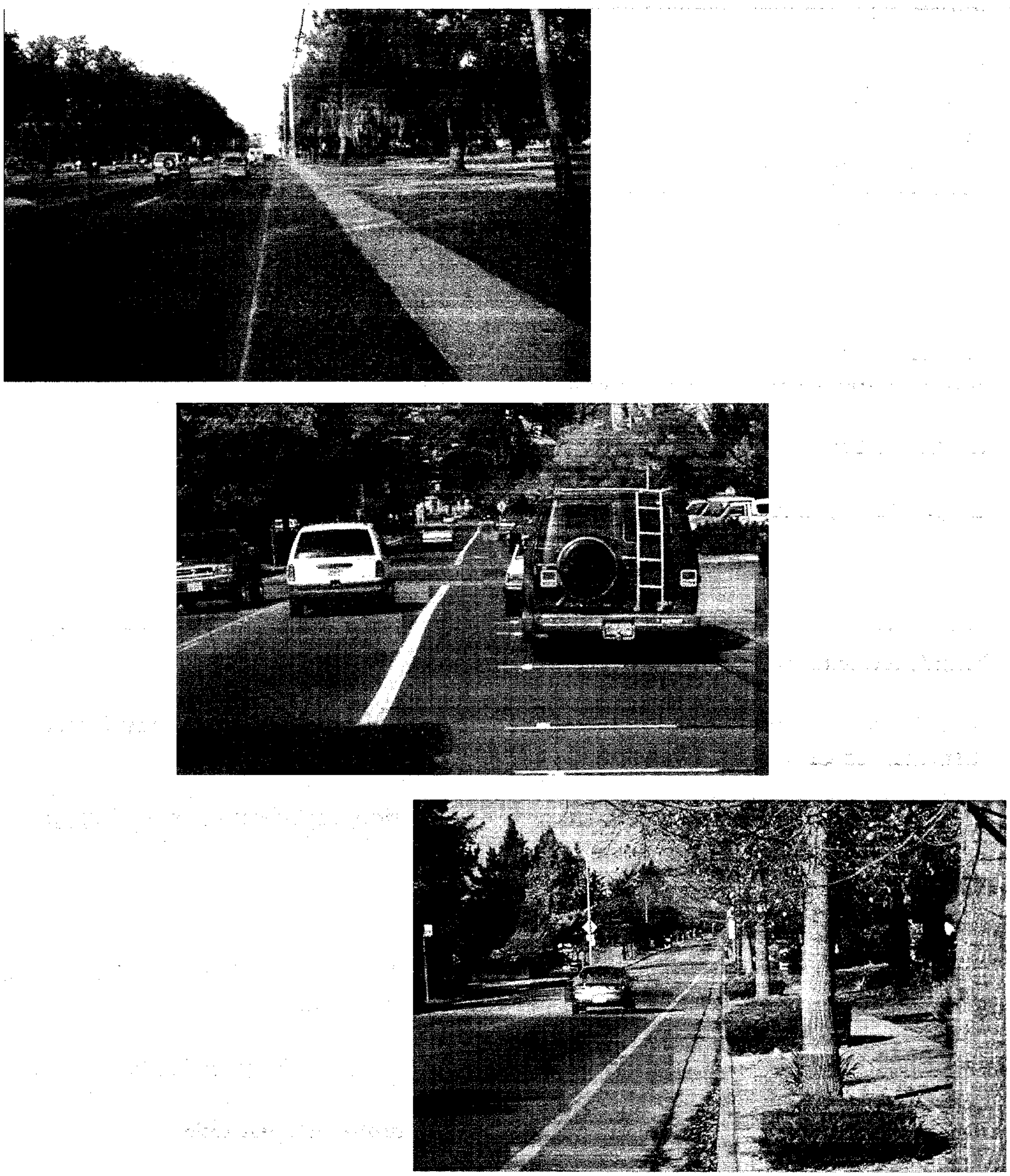

Figure 2.15 The bicycle compatibility index (BCI) allows practitioners to evaluate the capability of a variety of roadways to accommodate both motorists and bicyclists using geometric and operational characteristics such as lane widths, speed, and volume.

Real- World Examples:

Sorton/Walsh: In 1995, Slade McCalip of Orange County, NC, used this method to determine the suitability of their planned bicycle routes.

Dixon *(1995)* developed a bicycle level of service measure for use in the Gainesville Mobility Plan Prototype, which is the draft Congestion Management System plan for Gainesville, Florida. The LOS combines the bicycle performance measures researched by Epperson/Davis and Sorton/Walsh and the specific needs of the plan. The combined approach provided the jurisdiction with a measure that considers not only on-street facilities but also off-street projects. The corridor segments with low-LOS ratings (i.e., LOS E or F) tended to correspond with the Gainesville Urban Area Bicycle Advisory Board list of priority projects.

FHWA: This report used videotaping to capture images from roadway segments, which is similar to the Sorton/Walsh method.

Contacts/Source:

David Harkey, Donald Reinfurt, Matthew Knuiman, J. Richard Stewart, and Alex Sorton (authors), University of North Carolina, Highway Safety Research Center, 730 Airport Road, CB #3430, Chapel Hill, NC 27599.

David Mozer, Calculating Multi-Mode Levels-of-Service, International Bicycle Fund, http://www.halcyon.com/fkroger/bike/los.htm.

Alex Sorton, Transportation Engineering Division, Northwestern University Traffic Institute, 405 Church St., Evanston, IL, 60208.

Thomas Walsh, Madison Department of Transportation, 215 Martin Luther Ring, Jr. Boulevard, Madison, WI, 53701-2986.

Publications:

Dixon, Linda, Adopting ***Corridor-Specific Performance Measures*** *for* ***Bicycle and Pedestrian Level*** *of* ***Service,*** Transportation Planning, Volume XXII, No. 2, Summer 1995.

Federal Highway Administration. ***Development of the Bicycle Compatibility Index: A Level-of-Service Concept,*** Volume I: Final Report. Publication No. FHWA-RD-98-072, U.S. Department of Transportation, FHWA, McLean, Virginia, August 1998.

Mozer, David, ***Calculating Multi-Mode Levels-of-Service,*** International Bicycle Fund, http://www.halcyon.com/fkroger/bike/los.htm, 1994.

Sorton, Alex and Thomas Walsh, ***Bicycle Stress Level as a Tool To Evaluate Urban and Suburban Bicycle Compatibility,*** Transportation Research Record 1438, 1994.

Evaluative Criteria: How Does It Work?

Performance:

Sorton/Walsh: The method is easy to use. Although it does not mention pavement condition factors, pavement condition seems to play an important role for cyclists' ability to ride predictably without trying to avoid cracks, potholes, utility covers, etc.

Mozer: The method is similar to Sorton/Walsh. The web page information is not well written nor comprehensive. The Sorton/ Walsh method seems to be better researched.

FHWA: The method is a compilation of several approaches, mainly Sorton/Walsh. Although the method is new and lacks real world examples, it is the most comprehensive of all the bicycle facility methods that analyze supply and has been validated through surveys of bicyclists.

Use of Existing Resources:

Sorton/Walsh and *Mozer:* The methods use peak-hour or daily traffic counts, motor vehicle speeds, and curb-lane widths on the respective streets as well as parking turnover rates, heavy vehicle volumes, and the number of driveways.

FHWA: The method uses peak-hour or daily traffic counts, motor vehicle speeds, and curb-lane widths on the respective streets as well as parking turnover rates, heavy vehicle volumes, and number of right-turning vehicles. Some of these data may be obtained from local traffic data bases. or previous traffic studies, while others may require additional field data collection efforts. The method also requires an inventory of existing bike lanes.

Travel Demand Model Integration:

The methods have not been designed to be integrated with travel demand models.

Applicability to Diverse Conditions:

Sorton/Walsh: The research does not include roadways with bicycle lanes. The authors believe that the speed and width variables would drop for comparable streets that had bicycle lanes. For example, a street with a bicycle lane would not require as large a curb-lane width as a similar street without bike lanes.

Mozer: The method focuses on bicycle lanes and is not sufficient for bicycle paths.

FHWA: The method allows for analysis of roadways with bike lanes.

Usage in Decision-Making:

The methods describe current conditions for bicycling and can be used to prioritize facilities or specific facility design treatments.

Ability to Incorporate Changes:

The formulas are set up in a modular fashion making it easy to revise various components.

Ease-of-Use:

Sorton/Walsh: Orange County, NC, found the method easy to use.

FHWA: The inputs and procedures are not complex, and the BCI descriptions are easy to follow.

Comments:

Two previous attempts to gauge the "bicycle friendliness" of a roadway include:

1. The Bicycle Safety Index Rating (BSIR) developed by Jeff Davis in 1987, addresses many of the same factors as the BCI, but is based on the subjective opinions of the surveyors (rather than objectively measurable statistics) and does not weight the relative importance of different factors. BSIR, in a slightly modified form, is also known as the Roadway Condition Index (RCI); see Horowitz (1996).

2. The Bicycle Interaction Hazard Score (IHS), developed in 1994 by Bruce Landis, was designed to employ more objectivity in assigning values to different conditions as well as addressing a greater number of conditions (Landis, 1994).

Two additional authors have discussed attempts to determine roadway suitability for bicyclists. Eddy (1996) discusses how a suitability study might be done. Epperson (1994) presents a brief history of approaches to determining bicycle LOS.

John Forester's comment about Sorton's (and similar) methods: "These systems are not only scientifically erroneous, they are politically dangerous. 'That is, they emphasize the wrong things to produce a politically popular but scientifically erroneous plan that merely aggravates the existing situation in which people are unduly frightened of the most minor of conditions and don't pay attention to those which are much more important. The effect is to instill in the public to an even greater extent the exaggerated fear of bicycling in same-direction traffic and thereby jeopardize both safe and efficient bicycling and our rights to do it." (http://www.johnforester.com) Forester feels that the only factor to consider would be pavement condition.

On an Internet discussion list, other respondents on this topic mentioned the need for more focus on the following: (1) pavement conditions; (2) intersection density; (3) intersection volume; and (4) visual clutter such as signs, bus benches, and traffic control boxes.

Supply Quality Analysis:

■ 2.16 Pedestrian Compatibility Measures

Descriptive Criteria: What is It?

Categories:

☐ Bicycle ☒ Pedestrian ☐ Facility-Level ☐ Area-Level

Authors and Development Dates:

Mozer (1994); Dixon (1995)

Purpose:

Pedestrian compatibility measures, including stress level and level-of-service indicators, measure the suitability of roads, sidewalks, or other pathways for pedestrian travel. These methods describe current conditions for pedestrians rather than forecasting potential demand. The measures combine factors such as motor vehicle traffic characteristics, sidewalk width, and aesthetic quality of the environment into an index of overall suitability for pedestrian travel.

Mozer: The purpose of this method is to determine the current conditions of specific pedestrian facilities using level-of-service measures that describe the facility's stress level.

Dixon: This method measures the pedestrian performance of specific roadways, especially collectors and arterials where vehicle speeds and volumes may create a greater hazard to pedestrians. The pedestrian LOS measurements allow planners to obtain a facility inventory that highlights deficiencies, improvements, and results.

Structure:

Mozer: To determine the level-of-access of street segments for pedestrian use, this method uses four primary factors: walk area width-volume, walk area-outside-lane buffer, outside-lane traffic volume, and outside-lane motor vehicle speed; and three secondary factors: walk area penetrations, heavy vehicle volumes, and intersection wait-time.

Dixon: The method uses the following criteria to determine the pedestrian LOS for specific roadway segments (a bicycle LOS can also be computed from similar data):

- Basic facility provided (based on continuity, width, etc.);
- Conflicts;
- Amenities;
- Motor vehicle LOS;

- Maintenance; and
- Multimodal provisions (presence of Travel Demand Management measures).

A certain number of points are assigned for each level of these variables. The following measures are then computed:

- Segment score: the sum of points in the six categories;
- Segment weight: segment length/corridor length;
- Adjusted segment score: segment score multiplied by segment weight; and
- Corridor score: sum of adjusted segment scores in corridor.

Calibration/Validation Approach:

Mozer: No calibration or validation approach was mentioned.

Dixon: Dixon tested the method on five arterial roads and one collector road in Gainesville, FL, which resulted in LOS ratings of C, D, and E. Pedestrians in the area felt the scores adequately reflected the existing conditions of these corridors.

Inputs/Data Needs:

Mozer: The four primary factors require the following specific data needs.

Walk area Width-Volume:

- Peak-hour pedestrian volume;
- Non-pedestrian mode split such as bicyclists, skaters, etc.;
- Walk area width (meters);
- Travel pattern (equals "1" if one-way and "2" if bi-directional); and
- Whether the facility meets the Americans with Disabilities Act requirements.

Walk area-Outside Lane Buffer Factor:

- Walk area-outside lane buffer width; and
- Aesthetic quality (living or non-living material).

Outside-Lane Volume:

- Peak-hour volume per lane;
- K-factor: assumed as 10 percent for urban areas; and
- Number of lanes.

In addition, secondary variables are as follows:

- Walk area penetrations (based. on number of driveways, average peak-hour penetrations per driveway, and average distance between driveways);
- Heavy vehicle volumes (percentage is added to the primary LOS subtotal); and
- Intersection wait-time (a percent of a minute is added to the primary LOS subtotal).

Dixon: See "Structure" for data requirements.

Potential Data Sources:

Local street and traffic data are required.

Computational Requirements:

Mozer and *Dixon:* Minimal computational requirements are needed.

User Skill/Knowledge:

Mozer and *Dixon:* An understanding of basic traffic data is required.

Assumptions:

Both methods assume that pedestrian level-of-service can be adequately characterized using the indicated data.

Facility Design Factors:

Mozer: This method focuses on the facility design using volume, speed, and outside-lane width as the primary variables.

Dixon: The pedestrian LOS considers pedestrian facility continuity, conflicts, amenities, maintenance, and motor vehicle LOS as primary LOS factors.

Output Types:

Mozer: The method uses LOS criteria to rank the suitability of specific facilities for pedestrians. The criteria are as follows:

A – The facility is reasonably safe for children 10 years or older and for adults.
B – The facility is adequate for users with basic skills and traffic knowledge.
C – The facility requires an intermediate skill level and traffic knowledge.
D – The facility requires a more advanced skill level and traffic knowledge.
E – The facility is not suitable for pedestrian travel.

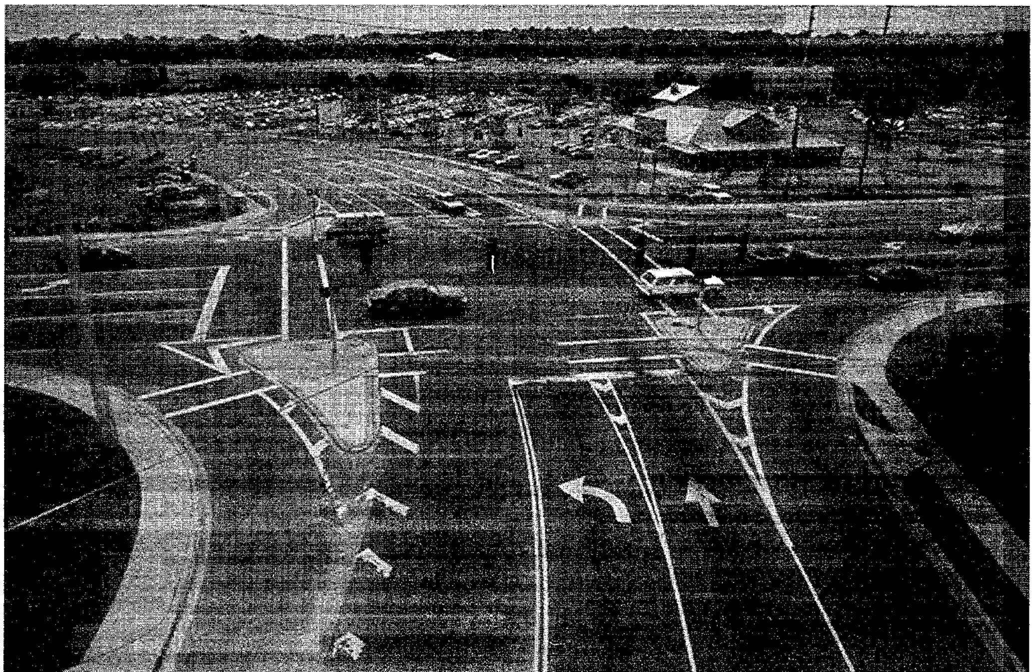

Figure 2.16 Pedestrian compatibility measures describe the suitability of roads, sidewalks, and other pathways for pedestrian travel.

Each primary factor is ranked on a scale of one to five according to its stress level. The stress levels correspond with the LOS measures. For instance, a street segment with a walk area width-volume of "3" would have a LOS of "C."

Dixon: The roadway segments are ranked on a scale of one to 21. The points from the six pedestrian LOS categories are added together to obtain the Segment Score. A Segment Weight is then calculated by dividing the segment length with the corridor length. The Adjusted Segment Score is obtained by multiplying the Segment Score with the Segment Weight. The sum of the Adjusted Segment Scores makes it possible to obtain the Corridor Score.

The Adjusted Segment Scores correspond to the following LOS performance measures: an LOS of "D" or higher represents a facility that is suitable for pedestrians; an LOS of "D" provides the minimum facility needed without amenities; a higher LOS may be useful if the facility is multi-use to account for bicycle, skater, and pedestrian interactions.

Real World Examples:

Mozer: The article does not mention a real world example.

Dixon: The method was used in the Gainesville Mobility Plan Prototype, which is the draft Congestion Management System plan for Gainesville, Florida.

Publications:

Mozer, David. *Calculating Multi-Mode Levels-of-Service,* International Bicycle Fund, http://www.halcyon.com/fkroger/bike/los.htm, 1994.

Dixon, Linda. *Adopting Corridor-Specific Performance Measures for Bicycle and Pedestrian Level of Service,* Transportation Planning, Vol. XXII, No. 2, summer 1995.

Evaluative Criteria: How Does It Work?

Performance:

Mozer: The method is easy to use. Nevertheless, it does not address facility condition or continuity. The method is similar to Sorton/Walsh for bicycle stress levels.

Dixon: The method uses data that is easily accessible and is applicable for both pedestrian paths and sidewalks. The method is used, to produce pedestrian facility inventories concerning their quality but does not attempt to forecast facility demand.

Use of Existing Resources:

Mozer and *Dixon:* Some data may be available from local traffic data bases and road inventories. Other data, such as pedestrian amenities, may require site-specific collection efforts.

Travel Demand Model Integration:

Mozer and *Dixon:* The methods have not been designed to be integrated with travel demand models.

Applicability to Diverse Conditions:

Mozer and *Dixon: The* methods focus on pedestrian sidewalks but do not give a sufficient method for describing the Level of Service of off-street pedestrian paths.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

Mozer and *Dixon:* The formulas are set up in a modular fashion making it easy to revise various components.

Ease-of-Use:

The methods are relatively easy to apply assuming that the required data can be obtained.

Supply Quality Analysis:

■ 2.17 Environment Factors

Descriptive Criteria: What is It?

Categories:

•zl Bicycle •I Pedestrian □ Facility-Level ⊠ Area-Level

Purpose:

Pedestrian and bicycle environment factors describe the friendliness of an area (such as a city block, census tract, or traffic analysis zone) for walking and/or bicycling. Pedestrian and bicycle environment factors have been developed primarily for use in regional travel models, where they are applied at a zonal level to predict mode choice and/or automobile ownership. These factors may be used to predict trips that are made by transit as well as entirely by non-motorized modes, since the likelihood of making a trip by transit may be influenced by the quality of the pedestrian environment around transit stations. Environment factors can also be used to prioritize areas for pedestrian or bicycle improvements, based on their rating.

Structure:

Environment factors are quantitative and may be a composite of a number of quantitative descriptors and/or subjective factors that have been quantified through an ordinal rating. Examples of factors considered include lane or sidewalk width, street continuity, topography, and the aesthetic quality of the environment. The specific factors included, and the means of aggregating them into an overall index, vary according to the application.

Portland's *Pedestrian* Environment *Factor (PEF),* developed for use in its regional travel model, includes four elements:

- Sidewalk availability;
- Ease of street crossing;
- Connectivity of street/sidewalk system; and
- Terrain.

Each zone is ranked for each element on a scale of zero to three, with highernumbers representing higher quality pedestrian environments, so the overall PEF can range from 0 to 12. A Pedestrian and Bicycle Environment Factor (PBEF) includes an additional three-point rating for bicycle facilities, so the PBEF can range from 0 to 15.

Montgomery County's *PBEF* includes five elements:

- Amount of sidewalks;
- Land use mix;
- Building setbacks;
- Transit-stop conditions; and
- Bicycle infrastructure.

Each factor can be rated at various levels for which specific fractional points are assigned (e.g., 0.00 for "little or no bicycle infrastructure," 0.05 for "some bicycle paths or routes," 0.10 for "many bicycle paths, lanes, or routes forming network'), yielding an overall PBEF of between zero and one for each zone.

A "*Transit Friendliness* Factor" developed to predict auto vs. transit mode choice in Raleigh, NC includes ratings on a scale of one through five for four elements:

- Sidewalk availability;
- Street crossings;
- Transit amenities; and
- Patron proximity to destinations.

Calibration/Validation Approach:

In theory, the elements included in each factor, and the weights applied to each element, could be validated through actual surveys of pedestrians or bicyclists to determine which factors are most important. Validation of the factors has not been performed in practice.

Inputs/Data Needs:

Various local land use and environmental data are required, according to the elements contained in the index.

Potential Data Sources:

Some data may be obtained from data bases of land use or facility characteristics (i.e., presence of sidewalks by street segment). Other data may need to be collected through fieldwork.

Computational Requirements:

Computational requirements for environment factors are minimal.

User Skill/Knowledge:

Knowledge of local land use and/or facility data bases is required. Also, in many cases, field data collection will be subjective and require judgment on the part of the observer.

Assumptions:

It is assumed that the elements contained in the environment factor adequately represent the attractiveness of the area to bicyclists or pedestrians, i.e., correlated with the traveler's decision to bicycle or walk. Furthermore, with combined bicycle and pedestrian environment factors, it is assumed that the same elements of environmental quality influence both bicycling and walking in the same manner.

Facility Design Factors:

A variety of factors can be considered. Examples of factors used include lane or sidewalk width, street continuity, topography, and the aesthetic quality of the environment (see "Structure" for further details). The factors included are generally limited by data availability.

Output Types:

The result is a numerical rating of the friendliness of an area for bicycling and/or walking.

Real-World Examples:

A Pedestrian Environment Factor has been developed and applied to the regional travel model in Portland, OR, and modified versions have been applied in Sacramento, CA, and Washington, DC. Montgomery County, MD, has developed a different Pedestrian/ Bicycle Environment Factor for use in its travel model. The application of factors in Portland has been described in 1,000 Friends of Oregon (1992 – 1997), Cambridge Systematics (1994), and Rossi (1993). The application of factors in Montgomery County has been described in Cambridge Systematics (1994). The application of factors in the Washington, DC region has been described in Chesapeake Bay Foundation, et al. (1996).

Evans, Perincherry, and Douglas (1997) developed a "Transit Friendliness Factor" describing the quality of pedestrian access to transit. This factor was applied in a sketch-planning mode choice model for the Triangle Transit Authority in Raleigh, NC.

Several research efforts have sought to identify the effects of various site design, neighborhood characteristics, and other environmental factors on travel behavior. The results of such research could be useful in determining which elements to include and which weights to assign, and in constructing environment factors.

Contacts/Source:

John Evans (Transit Friendliness Factor): Parsons Brinckerhoff Quade and Douglas Inc., Baltimore, MD

Michael Replogle (environment factors in Montgomery Co., MD, and Washington, DC): Environmental Defense Fund, Washington, DC.

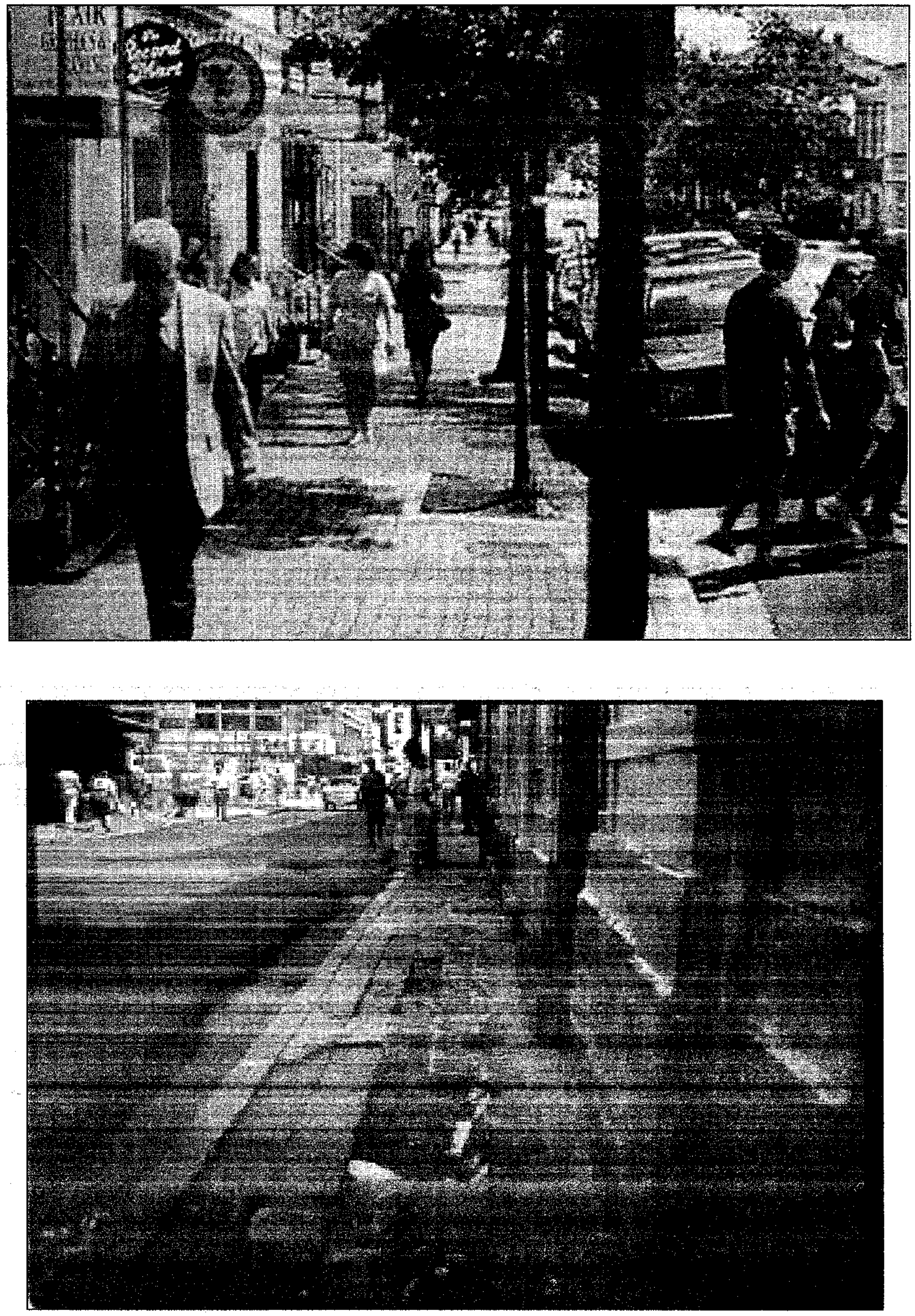

Figure 2.17 Pedestrian environments vary widely in their quality.

Tom Rossi (environment factors in Portland, OR, and Washington, DC): Cambridge Systematics Inc., Cambridge, MA

1,000 Friends of Oregon (environment factors in Oregon): http://www.teleport.com/~friends/Lutraq2/Docs.htm

Publications:

Cambridge Systematics, *Inc. Short-Term Travel Model Improvements,* Travel Model Improvement Program. U.S. Department of Transportation; DOT-T-95-05, pp. 2-l to 2-7, October 1994. (1994a).

Chesapeake Bay Foundation, Environmental Defense Fund, et al. *A Network of Livable Communities: Evaluating Travel Behavior Effects of Alternative Transportation and Community Designs for the National Capital Region.* Washington, DC, May 1996.

Evans, John E., IV. Vijay Perincherry, and G. Bruce Douglas, III. *Transit Friendliness Factor: An Approach to Quantifying the Transit Access Environment in a Transportation Planning Model.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #971435, January 1997.

Rossi, Thomas. T. Keith Lawton and Kyung Hwa Kim. *Revision of Travel Demand Models to Enable Analysis of Atypical Land Use Patterns.* Cambridge Systematics, Inc. and Metropolitan Service District, May 1993.

1,000 Friends of Oregon. *Making the Lund Use Transportation Air Quality Connection: Volume 4A, The Pedestrian Environment.* Portland, OR, 1993. Available at http://www.teleport.com/~friends/Lutraq2/Docs.htm.

Evaluative Criteria: How Does It Work?

Performance:

Incorporation of environment factors has led to improvements in the Portland and Montgomery County regional travel models in terms of predicting auto versus non-auto mode split.

Inclusion of a Transit Friendliness Factor in Raleigh, NC, significantly improved the performance of the model at predicting auto versus transit mode choice.

Use of Existing Resources:

These methods require some new data collection.

Travel Demand Model Integration:

Environment factors are generally designed to be used in travel models. A factor composed of any number of specific elements could be included in modeling, if data on the factor could be collected and aggregated at a zonal level compatiblewith existing local travel models.

Applicability to Diverse Conditions:

The elements included in the factors are generally relevant across regions and area types. However, specific local data collection efforts are required to develop the factors locally.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

Individual elements of the factors could be changed or updated without requiring new data collection for the other elements of the factor.

Ease-of-Use:

The factors require collecting and managing a relatively large amount of data, but they are easy to understand and no special skills are required. However, they cannot be used by themselves to forecast bicycle or pedestrian travel. Incorporation of the factors into mode choice or regional travel models requires capability for such modeling.

Supporting Tools and Techniques:

2.18 Geographic Information Systems

Descriptive Criteria: What is It?

Categories:

☒ Bicycle ☒ Pedestrian ☒ Facility-Level ☒ Area-Level

Purpose:

Geographic Information Systems (GIS) are tools for managing and analyzing data. GIS can be used to enhance bicycle and pedestrian demand forecasting and facility analysis by permitting spatially-based analysis, which might otherwise be difficult or impossible. GIS can also be used to display and communicate information relevant to bicycle and pedestrian planning.

Structure:

Broadly, GIS relate environmental and population data in a spatial framework, using location points, lines (commonly roadway links and corridors), and polygons (surface areas and analysis zones). These geographic values are linked to measurable environmental and population characteristics and analyzed by spatial relationship.

Within the field of transportation, GIS are employed as a mechanism for the physical inventory of transportation facilities, as a planning tool to relate available environmental, personal transportation and household characteristics data, as a spatial analysis tool for calculating distances and areas, as a network performance monitor, and as a vehicle for the graphic display of data and analysis in a geographic context.

Currently, non-motorized-oriented GIS applications serve a variety of functions:

- Inventory and evaluate facilities within the non-motorized network using existing condition indexing and evaluation methods. Roadway conditions, such as pavement condition, average traffic volume, and outside-lane width, are linked to specific network links. Analysis of this data and subsequent analysis can be displayed graphically in the form of a visual map.

- Establish spatial relationships between the location of roadway network links and their condition to off-network features (activity centers, etc.) and area population characteristics.

- Calculate and assign probabilistic gravity values of activity centers (trip generation or attraction) to geographic areas, roadway links, and location points. Roadway links are assigned a composite score based on their proximity to trip generators and attractors.

This is particularly useful in the trip assignment phase of the four-step transportation demand model.

- Compare current conditions to future projections of travel and conditions. The effects of changes in variables of underlying models can be illustrated using a GIS. For example, a GIS could produce a series of displays or maps that show the negative impact of increased motor vehicle flows on roadway conditions for bicyclists, expressed either as a decrease in level of service or increase in condition index value.

- Illustrate impacts and calculate costs of physical improvement scenarios in a network context. A GIS can quantify improvements in level of service, condition index, or another condition evaluation by comparing present values to projections identified in planning and modeling scenarios. A GIS can relate projected physical improvements for each link to roadway link length, estimate improvement costs per link, and calculate an aggregate improvement cost. This is particularly useful in project phasing and budgeting.

- Assess total network performance and identify optimal routes. This use of GIS is currently limited by available technology, as it must be adapted from motor-vehicle-oriented network modeling applications.

- Produce printed maps (e.g., maintenance scheduling, project phasing, and user maps).

- Develop network measures (street density, connectivity, etc.) and land use measures (mix, balance) that can be related to the likelihood of walking or bicycling.

Using GIS applications requires the development of a foundation data base of geographic features within the study area, including municipal boundaries, geocoded roadway links, bodies of water, and others. This information becomes the base layer upon which subsequent layers of information and analysis will be superimposed. Additional layers can attribute values or data to established roadway links, identify and classify population groups (by income, housing value and tenure, etc.) and activity centers (by trip generation characteristic). Each layer can be manipulated individually, displayed on the computer screen in any combination or printed out to meet the needs of the analyst.

Calibration/Validation Approach:

Input model calibration can be performed within the GIS. However, initial calibration of input models (spreadsheets, etc.) may require manipulations that are more easily performed outside the GIS.

Analysis of roadway conditions requires calibration to local conditions (terrain, climate, and rider behavior) and can be achieved through public involvement (stated-preference or attitudinal surveys) and testing (actual riding and rating of segments by citizen participants).

Visual inspection of computer display and printed output provides an additional level of validation and error-correction.

Inputs/Data Needs:

GIS applications require a base level of geographic data, including study boundary lines, subdivisions of the study areas (census tract or traffic analysis zone boundary lines) roadway segments, and other features within the **study** area.

Geospatial transportation facility files are based on a set of standard record types: link, node, point, area, geography, and attribute. Each of three spatial feature types — networks, point facilities, and areas — consists of an interrelated combination of these record types defining the geometry, topology, and attributes associated with a specific transportation or background feature. Specifically:

- **Transportation networks** are composed of four related record types: link, node, geography, and attribute. Examples of transportation networks are highways; public transportation, bikeways, railroads, and waterways.

- **Transportation point facilities** such as airports, transit terminals, and bicycle parking facilities require only two related record types: point and attribute.

- **Areas** are made up of three related record types: area, geography, and attribute. Features such as congressional districts, states, and national parks are examples of areas.

In addition to this base layer of data, information on roadway segment conditions and geocoded activity centers may be required parts of input models. The addition and display of recognizable features and landmarks can help orient non-technical planning staff and the public.

Potential Data Sources:

Geographic data are available from a range of sources, including the U.S. Department of Transportation's Bureau of Transportation Statistics (BTS). BTS distributes the Census Transportation Planning Package (CTPP) and the Census TIGER/line files, the most broadly used geospatial data sets.

The Census Bureau's Census Topologically Integrated Geographic Encoding and Referencing (TIGER) system automates the mapping and related geographic activities required to support the decennial census and sample survey programs of the Census Bureau starting with the 1990 decennial census. The TIGER/Line files contain data describing three major types of data:

- **Line features,** including roads, railroads, hydrography, miscellaneous transportation features, and selected power lines and pipelines right of ways;

- **Landmarks,** including point landmarks such as schools and churches and area landmarks such as parks and cemeteries; and

- **Polygons,** including geographic entity codes for areas used to tabulate the 1990 census statistical data locations of area landmarks.

The U.S. Geological Survey (USGS) produces geospatially correct quadrangles — digital images of an aerial photograph in which the displacement caused by both camera tilt and by terrain have been corrected. USGS quadrangles combine the image characteristics of a photograph with the geometric qualities of a map, allowing GIS users to link geospatial data to the photographic image. This real world imaging can be particularly useful in interfacing with nontechnical staff, public officials and citizens.

Most state and many metropolitan transportation agencies maintain supplementary GIS-compatible data on local features, roadway classification and lane widths, and other transportation-related features. Some local municipalities have begun gathering bicycle and pedestrian-specific feature information using global positioning system (GPS) technology. The GPS produces an accurate geospatial value for location features such as curb ramps, bicycle parking and multiple-use pathway facilities.

Computational Requirements:

GIS require specialized software applications (e.g., ARCView®, ARCInfo®, MapInfo®, and Maptitude®), geographic data base files, and spreadsheet models. Complex computation and detailed graphics displays utilized by GIS are more efficiently run on desktop personal computers with fast processors and large amounts of memory or on larger network servers or mainframe computers.

User Skill/Knowledge:

Effective use of GIS requires a relatively high degree of competence in relational data base management, aptitude for computer-based data manipulation, and a working understanding of the GIS application being used. Users must also be familiar with cartographic layout principles to produce printed output.

Assumptions:

GIS applications assume the validity of their input models (condition index, level of service, latent demand scoring, etc.). When using two or more analytical models simultaneously, it is assumed the operator has taken steps to register variables common among the models. It is further assumed that the base geographic and geocoded data are in a compatible format, and are valid in location and orientation.

Facility Design Factors:

Any number of facility condition variables can be assigned to each roadway link, such as functional classification, travel-lane widths, and pavement conditions. Analysis of these variables can yield a composite score or rating for each link. These composite scores can be compared to optimal or preferred targets (derived from planning methodology or general policy goals) to identify areas which may require facility design improvement.

Output of a GIS analysis can also be applied to facility design policies and paradigms. For example, the condition index variables developed in the Buffalo, NY, area (Beltz and Burgess, 1998) were applied with modifications to the facility planning model detailed in the FHWA report *Selecting Roadway Design Treatments to Accommodate Bicycles* (FHWA, 1994) to produce a draft set of recommended physical improvements. Analysis using the FI-IWA methodology for "Group A" (advanced or experienced) bicyclists yielded a recommended facility — a wide curb lane 4.3 m in width. Beltz and Burgess employed a GIS to calculate improvement recommendations for each link in the Buffalo, NY, study area using this method (see "Real World Examples").

Output Types:

The primary outputs of a GIS are: (1) electronic graphic display of thematic layers of data (e.g., road network or population); (2) the printing of thematic maps of the geographic study area; (3) the calculation and assignment of values to geographic areas (e.g., census tracts or traffic analysis zones) based on population, land use, other characteristics; and (4) the calculation and assignment of values to roadway links and nodes (commonly, intersections) based on proximity to trip generator locations and populations, which may become a base for trip assignment in a classic four-step travel demand model.

Figure 2.18 GIS can be used to develop network measures (such as street density or connectivity) and land use measures (such as mix or balance) that can be related to the likelihood of walking or bicycling.

Real- World Examples:

Buffalo, NY - Beltz, Burgess and Landis employed a GIS as a base for roadway condition analysis using the Bicycle Level of Service (BLOS) in an examination of a 1,300-km study network (center line km) in the Buffalo, NY area for the Niagara Frontier Transportation Commission. Roadway condition data were collected and attributed to individual roadway links. Each link was evaluated using the BLOS scoring methodology, inspected for validity, and assigned a composite score. BLOS scores were applied to the LOS A through F scale (with A being most accommodating and F being total lack of accommodation), and scale values for each link were themed by color for visual inspection. Through public involvement and consultant recommendations, target levels of accommodation were designated: minimum LOS C for all links and LOS B for certain priority routes and where opportunities exist.

A secondary analysis of roadway condition data using criteria from FHWA (1994) yielded a set of draft improvement recommendations specific to each link in the study network. Thematic maps were inspected by agency transportation planners, and final recommendations were made factoring in various policy initiatives study goals and other factors (e.g., parking requirements and available lane widths).

Warwick, RI – The Warwick Bicycle Network Study (Beltz and Burgess, 1998) employed a smaller scale application of GIS methods. Trip generation estimates were calculated as a function of employment, school enrollment and total population for traffic analysis zones adjacent to the study alignment. Composite trip generation scores were then attributed to network segments within the areas of influence of trip generators. The results of this analysis were compared to the existing designated bicycle route network. Alternative route designations suggested where undesignated roadway links' potential scored higher than a parallel or adjacent designated route. The results of this sketch planning effort served as the basis for final facility improvement recommendations.

Seattle, WA – The city of Seattle has created inventories of its pedestrian facilities using GIS, including existing sidewalks and sidewalk deficiencies; locations of marked crosswalks; conditions, locations, and needs for curb ramps in neighborhood commercial areas, and locations where curb bulbs are needed. This information is being matched to elementary school walking zones (305 m around each school), neighborhood service providers (e.g., libraries), and neighborhood business districts. Locations containing all three of these land uses are top priority; those containing none are lowest priority. Using the GIS inventory, recommended walking route maps for schools have'been developed for each of the 60 elementary schools in Seattle. City program managers find that providing GE-based products (maps) to the public generates increased demand for facility improvements and adds priority to proposed projects.

Orange County, CA – Hsaio (1997) of the Orange County Transit Authority used GIS techniques to analyze pedestrian accessibility to transit in Orange County, CA, using the actual street network and population information by census tract. Among other uses, the technique can be used to estimate the impacts on transit catchment population (and potentially mode choice) of improvements to the pedestrian network.

Fort Collins, CO – The city of Fort Collins, CO, used a GIS to monitor level of service (LOS) for pedestrians using a five-point LOS criteria: directness, continuity, street crossings, visual interest and amenity, and security. Areas in the city were assigned one of four designated types: pedestrian district, activity corridor, activity center, and transit route. A separate LOS threshold was set for each area type for the following factors:

- Directness;
- Continuity;

- Street crossings;
- Visual interest and amenity;
- Security;
- Pedestrian district;
- Walking to schools/parks;
- Activity corridors and centers; and
- Walking to/from transit.

Montgomery *County, MD* – The Maryland-National Capital Park and Planning Commission (M-NCPPC) used indices for bicycle and pedestrian-friendliness, similar to the Portland, OR, Pedestrian Environment Factor. Each Traffic Analysis Zone (TAZ) is assigned a value according to sidewalk quality (six point scale), land use mixing (four point scale), building orientation, transit-stop conditions, and bike infrastructure. The M-NCPPC maintains a county-wide inventory of sidewalks and transit stops using a GIS.

Ames, IA – Mescher and Souleyrette (1996) used a GIS to assign bicycle condition index (BCI) values to the city street network of Ames, Iowa. The purpose of the case study was to: (1) identify optimal bicycle routes; and (2) compare them to existing and proposed bicycle route locations. The Ames BCI was developed utilizing the Delphi technique, using the Internet to coordinate expert panelist responses. The resulting BCI was used to assign penalty values to individual roadway links according to each of 14 criteria. The GIS then calculated composite scores for each roadway link included in the study.

The researchers developed an optimal route-planning tool, using a shortest-path FORTRAN algorithm, that minimizes the sum of (negative) link scores between two identified nodes. Optimal route calculations between nodes were then visually inspected for validity (based on general knowledge of bicyclist route preferences), and appropriate changes in variable weighting made. The outputs of the optimal route calculations were then compared to existing bicycle routes. In test cases, optimal routes scored significantly better than existing routes, using the identified criteria.

Melbourne, Australia – Wigan, Richardson and Brunton (1998) used a GIS to investigate trip generation characteristics of an existing multiple use trail (Lower Yarra Trail – a well-connected and promoted facility) based on user surveys, adjacent population demographics, and connectivity to these residential areas. The results of this analysis then became the basis for predicting potential levels of use at another multiple use trail (the Maribrynong Trail, which does not benefit from equivalent access and public promotion), assuming similar conditions existed.

From user surveys, Wigan et al., developed a trip length distribution model and trip generation rates for postal code zones within the study area. These rates were compared to population densities in postal code areas at various distances from the Maribrynong Trail and calculated distances from the trail to the postal area centroids (geographic center of the polygon area). Using this sketch plan method, researchers estimated a potential 500 percent increase in use, if improvements in facility access and promotion were undertaken.

Guelph, Ontario – Aultman-Hall, Hall, and Baetz (1997) use a GIS network data base to determine the characteristics of 397 routes used by commuter cyclists in Guelph, Ontario, and to compare them to the shortest path routes between each origin and destination. The analysis provides useful insight for understanding factors affecting travel behavior such as grades, intersections, etc. The study recommends different priorities for improving conditions for existing cyclists and for attracting new cyclists to the network.

Use ***of GIS in*** Travel ***Behavior Research –*** In addition to assisting with realworld planning applications, GIS has facilitated research into factors influencing bicycle and pedestrian travel behavior.

Frank et al. (1997) developed measures of pedestrian friendliness using Census TIGER files, and related these measures to the likelihood of walking or taking transit in the Seattle, WA, region. The number of census blocks per hectare in a census tract was used as a proxy for the level of connectivity and density of the street network. Related work has been conducted at the Georgia Institute of Technology (Wineman, unpublished) to develop and test topological measures of the street network from TIGER files and relate these to pedestrian flows. These measures have been found to be effective at predicting the distribution of pedestrian flows on the street network. Other travel behavior researchers (c.f. Loutzenheiser, 1997; Kockelman, 1996) have also made extensive use of GIS in analyzing land use data and relating it to travel behavior.

Contactsl Source:

Bill Barber: Metropolitan Service District (Portland, OR)

Bruce Burgess, Peter Moe: Bicycle Federation of America (Washington, DC)

Lawrence Frank: Georgia Institute of Technology, City Planning Department (Atlanta, GA)

Shirley Hsiao: Orange County Transit Authority (Orange, CA)

Bill Jack: City of Seattle, Transportation Department (Seattle, WA)

Bruce Landis: Sprinkle Consulting Engineers (Tampa, Florida)

Phillip Mescher: Iowa Department of Transportation (Ames, IA)

Matthew Ridgeway: Fehr and Peers Associates (Lafayette, CA)

Timothy Traybold: Niagara Frontier Transportation Commission (Buffalo, NY)

Marcus Wigan: Oxford Systematics (Heidelberg, Australia)

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Onsrud, Harlan J. and G. Rushton. Sharing Geographic Information, Rutgers University, Center for Urban Policy Research, New Brunswick New Jersey, 1995.

Wigan, Marcus, Anthony Richardson, and Paris Brunton. *Simplified Estimation of Demand for Non-motorized Trails Using GZS.* Presented at the 1998 Transportation Research Board Annual Meeting, Paper #981203, January 1998.

Evaluative Criteria: How Does It Work?

Performance:

GIS enhances the effectiveness of spreadsheet modeling techniques by providing analysts with a visual-map display of conditions and test forecasts. GIS also enables models to account for proximity — a major factor in non-motorized mode choice — and the clustering of conditions and target populations.

GIS applications depend on the validity and reliability of input models, and are limited to the forecasting capability of these other tools. GIS can be a useful reference in testing optimal route designation in trip-link assignment.

Use of Existing Resources:

GIS uses available geographic data (TIGER line files, geocoded Census data, U.S. Geological Survey data) supplemented by local feature data. However, some municipalities do not have a complete GIS-coded inventory of facilities. Some features within the study area may also need to be identified and assigned a geographic value manually.

Travel *Demand Model Integration:*

Network analysis tools currently available with GIS applications are not sufficiently robust to enable full integration.

Applicability to Diverse Conditions:

GIS is a (spatial) relational data base; individual inputs (i.e., roadway condition indices, latent demand scoring) can be adapted to reflect local conditions and include special factors or characteristics.

Usage in Decision-Making:

GIS is particularly useful in providing composite visual representation of fairly complex underlying model calculations. Citizens, public officials, and agency staff alike can easily understand information provided in printed maps and illustrations.

Maps are extremely useful at agency staff work sessions and public meetings, where participants can identify barriers and opportunities for improvement, and better perceive and address issues related to network development, connectivity, and priorities without having a background in GIS.

GIS can be used to develop comprehensive proposals for physical improvements, including detailed design and cost information. Lists of proposed projects, ranked by priority and including data on the impacts of improvements, can aid bicycle and pedestrian practitioners in transportation and capital improvement program development, program budgeting, and long-range planning.

Ability to Incorporate Changes:

Changes may be made within the input databases and spreadsheets, and in the thematic analysis within the GIS. However, since multiple input sources are likely to be used, changes in one input data set may require a corresponding change in one or more related data sets.

Ease-of-Use:

GIS is becoming more widely used and understood by transportation professionals. Many planners with experience with spreadsheet-based modeling are discovering advantages to supplemental use of GIS, and becoming more adept at its use. However, GIS applications require an understanding of both spatial analysis concepts and the specific software being used.

GIS software applications have not reached the same level of cross-compatibility as spreadsheets; users may experience some barriers to data-sharing among State, regional, and local agencies.

Comments:

GIS has not yet been used to its full potential to relate population and activity center characteristics (as they relate to personal choice factors and demand) to the roadway network, including non-motorized pathways (physical conditions, capacity, and route choice decision making). Nor has it been fully used to assess the performance of the network as a system of interconnected links.

Attempts at using existing network performance models for non-motorized network analysis have ended with unsatisfactory results. (e.g., Matthew Ridgeway, use of TransCAD in Arcata, Calif.)

Additionally, start-up costs of more complex GIS may be beyond the reach of some municipalities. The city of Seattle spent several million dollars in implementing a new GIS. However, simpler systems can be implemented more economically, provided geographic feature data are available.

The inventory of roadway conditions related to bicycle and pedestrian travel is not routinely gathered in detail sufficient to support subsequent analysis. Supplemental data collection may be cost-prohibitive.

Supporting Tools and Techniques:

■ Preference Surveys

Descriptive Criteria: What is It?

Categories:

•J Bicycle ☒ Pedestrian ☒ Facility-Level ☒ Area-Level

Purpose:

Preference surveys are surveys of actual or potential users, in which respondents are asked to express an attitude or make a choice as to how they would act under certain conditions.[1] Preference surveys can have a wide range of uses in bicycle and pedestrian planning, such as:

- Estimating the potential mode choice impacts of a facility improvement or policy change;
- Determining relative preferences for different types of improvements; and
- Measuring attitudes and other personal variables which influence the decision to bicycle or walk.

The level of sophistication involved in preference surveys can vary significantly. At a basic level, survey results can be used directly to prioritize projects or to estimate the impacts of an improvement. Alternatively, more sophisticated surveys can be developed which can be used alone or in conjunction with other data to develop quantitative models of behavior. The advantages and disadvantages of modeling behavior based on survey results are discussed separately, under "Discrete Choice Models," Method 2.5.

Structure:

Two levels of preference surveys can be identified:

1. **"Attitudinal"** surveys ask respondents directly how they would respond to various actions (i.e., would they bicycle if bike lanes were available), or ask them to rate or rank their preferences for various improvements. Attitudinal surveys are relatively easy to design and implement and have been widely used to estimate the potential impacts of bicycle and pedestrian improvements and to determine relative preferences for such improvements. However, attitudinal surveys often significantly overestimate the

[1] Preference surveys, as discussed in this document, are technically referred to as "stated-preference" surveys to distinguish them from "revealed-preference" surveys. Revealed preference surveys are used to observe actual behavior, for example trips made by household members, rather than asking respondents how they would behave in a hypothetical situation. Travel behavior as observed in the revealed-preference survey is then related to various characteristics which influence travel decisions.

response to a bicycle or pedestrian improvement, since people tend to be more likely to state that they will change their behavior than to actually do so. Attitudinal surveys tend to be better suited for evaluating relative preferences and for estimating the maximum possible response to an action, rather than predicting actual shifts in travel demand.

2. "Hypothetical choice" surveys overcome many of the biases of attitudinal surveys by requiring respondents to make choices between hypothetical alternatives with varying attributes. Hypothetical choice surveys are generally used to develop discrete choice models and to estimate the relative importance of each attribute (time, cost, presence of bike lanes, etc.) in common terms. While hypothetical choice surveys, combined with discrete choice modeling, are becoming more widely used in non-motorized travel analysis, they have the disadvantage of requiring considerable time and expertise to implement. The choice of alternatives to be presented to each respondent must be made carefully to provide the desired relationships between the characteristics of hypothetical alternatives and the probabilities of choosing each alternative.

The results in terms of predicted mode split from the survey sample can then be applied to the general population to estimate total change in number of users as a result of an improvement. The results of preference surveys can also be combined with observed data on actual behavior to develop behavior models. This combined approach has two significant advantages: (1) the alternatives used for the stated-preference portion of the survey can be designed to pivot off the actual behavior of the respondent; and (2) the survey can be designed to provide calibration to reality as represented by what the traveler is currently doing. An example of this approach, as applied to transit access mode choice in the Chicago area, is discussed in the entry on "Discrete Choice Models: Transit Access," Method 2.7.

Calibration/Validation Approach:

Survey results, in terms of the percentage of people who would switch modes given an improvement, can be compared with the actual number of people switching modes in a case where the same improvement has already been implemented.

Inputs/Data Needs:

This method generally requires that a survey be conducted of actual and/or potential bicyclists or pedestrians who could benefit from the facility improvement or policy change in question. Alternatively, results of surveys conducted elsewhere can be utilized, if the issues addressed by the survey are applicable to the situation being analyzed.

The basic steps in conducting a preference survey include:

- Determining a sampling methodology. The sample should be representative of the people who are potentially affected by the action.
- Determining the type of survey instrument (mail, telephone, intercept, etc.).
- Designing the survey instrument.

- **Implementing the survey.**
- **Analyzing the survey results.**

Travel Survey

Instructions: This survey is to be completed by the household member age 16 or above who most recently had a birthday.

General Information

1. Including yourself, how many persons live in your household? ___ persons

2. Please indicate the number of household members in each age category:
   Numbers should add to the total number of household members given above.
   ___ ages O-4
   ___ ages 5-15
   ___ ages 16-20
   ___ ages 21-64
   ___ ages 65+

3. How many registered motor vehicles (cars, pickup trucks, motorcycles, etc) are owned by members of your household? ___ vehicles

4. Do you have a driver's license? (Circle one)
   1. Yes
   2. No

5. How far is it from your home to the nearest public transportation (bus stop, subway station, etc.)? (Circle one)
   1. NO PUBLIC TRANSPORTATION
   2. l-2 blocks (less than 1/8 mile)
   3. 3-4 blocks (1/8 to 1/4 mile)
   4. 5-8 blocks (1/4 to 1/2 mile)
   5. 1/2 mile but less than 1 miles
   6. 1 mile but less than 2 miles
   7. 2 miles or more

6. Do you have a bicycle that could be used for transportation? (Circle one)
   1. Yes
   2. No

Work Travel

7. Are you currently employed? (Circle one)
   1. Yes
   2. No → If No, skip to Question 15

8. How many days a week do you usually work?
   ___ days

9. About how far is your usual place of work from where you live? (Circle one)
   1. 0 miles (if work at home)
   2. Less than 1/2 mile
   3. 1/2 mile but less than 2 miles
   4. 2 miles but less than 5 miles
   5. 5 miles but less than 10 miles
   6. 10 miles but less than 20 miles
   7. 20 miles or more

10. What was your primary transportation for your most recent trip to work?
    Circle one. Primary transportation is the type that is used for the greatest distance.
    1. NOT APPLICABLE (worked at home)
    2. Carp001 or vanpool
    3. Drove alone in car or truck
    4. Drove car/truck with passengers
    5. Passenger in car or truck
    6. Motorcycle, scooter or moped
    7. Public transportation (bus, subway, commuter train, etc.)
    8. Taxi
    9. Bicycle
    10. Walk
    11. Other (describe) ___________

11. About how much time is usually needed to make this trip?
    ___ minutes

Figure 2.19 A bicycle and walking mode share survey.

Potential Data Sources:

Previous studies using preference surveys can be used as resources for bicycle and pedestrian planning in other areas. See "Publications" for existing preference survey data.

Computational Requirements:

Standard statistical software available for microcomputers can be used to analyze survey results.

User Skill/Knowledge:

Surveys of varying levels of sophistication can be developed.

Assumptions:

Use of preference surveys to estimate behavior changes assumes that people are able to accurately predict their response to a facility improvement or policy change. Frequently, when people are asked if they will change their behavior in the future, the responses significantly overpredict the number of people who actually change their behavior. Therefore, attitudinal surveys that simply ask people how they will respond in a given situation are not generally viewed as reliable (although they can at least give some indication of the relative response to various actions.) This problem can be largely eliminated through the use of carefully designed hypothetical choice experiments, combined with data on actual behavior if available, although respondents may still not be able to accurately judge what their true actions would be if faced with a realworld situation.

If survey results from other areas are used, it is assumed that external factors that may influence survey results, but which are not included in the survey, remain the same in both situations.

Facility Design Factors:

A variety of facility design factors can be analyzed. An advantage of the stated-preference survey method is that users can be asked questions specific to the design or policy factors under consideration.

Output Types:

The results of a survey can be summarized and presented in various formats. Examples of survey results include the percent of respondents who would switch to bicycling or walking if a particular improvement were made, and which improvements are regarded by respondents as being top priority.

Real-World Examples:

A variety of preference surveys have been conducted by States, MPOs, and other organizations. FHWA (1992) and Stutts (1994) document the results of many of these surveys and also discuss the advantages and disadvantages of this type of survey approach.

Moritz (1997) conducted a survey of 2,374 bicycle commuters in the United States and Canada. The survey includes socioeconomic and demographic information, commuting habits/trip characteristics, accidents, equipment and facilities used, relative danger by type of street, and motivation.

San Diego *County* in 1994 conducted a survey of 3,800 randomly selected people regarding use of and attitudes toward bicycling.

Contacts/Source:

William Moritz: University of Washington, Seattle, WA.

Jane Stutts: University of North Carolina – Highway Safety Research Center, 730 Airport Road, Chapel Hill, NC, 27514

Stephan Vance: San Diego Association of Governments, San Diego, CA.

Publications:

Federal Highway Administration (Stewart A. Goldsmith). Case *Study* No. *1: Reasons Why Bicycling and Walking Are Not Being* Used *More Extensively As Travel Modes.* National Bicycling and Walking Study, U.S. Department of Transportation (FHWA), Publication No. FHWA-PD-92-041, 1992.

Moritz, William E. *A Survey of North American Bicycle Commuters – Design and Aggregate Results.* Presented at the Transportation Research Board 76th Annual Meeting, Paper #970979, January 1997.

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Guidelines for survey design and implementation can be found in:

Cambridge Systematics and Barton-As&man Associates. *Travel Survey* Manual. Prepared for U.S. Department of Transportation and U.S. Environmental Protection Agency, 1996.

Dillman, D. *Mail and* Telephone *Surveys: The Total Design Method.* Wiley-Interscience:. New York, 1978.

See entries for 'Discrete Choice Models" (Method 2.5) for references to other preference surveys.

Evaluative Criteria: How Does It Work?

Performance:

Hypothetical choice surveys have been successfully used to estimate and calibrate models of tripmaking behavior. The performance of such models is discussed under 'Discrete Choice Models," Method 2.5.

The best use of attitudinal surveys may be for determining relative priorities for improvement. These surveys tend to be overly optimistic in estimating the actual number of new users of a facility (see "Assumptions").

Use of Existing Resources:

Use of survey data generally requires data collection efforts specific to the proposed project/policy actions. In some cases, a similar situation may be identified for which a survey has already been conducted.

Travel Demand Model Integration:

Behavior models based on hypothetical choice survey results can be integrated into travel demand models (see "Discrete Choice Models," Method 2.5).

Applicability to Diverse Conditions:

A survey designed for a specific situation can be adapted to a wide range of conditions. On the other hand, if data from existing surveys are used, it may not be safe to transfer the results of one survey from one situation to another. When people are asked how their behavior will change as a result of an action, their responses depend on a number of factors specific to the decision in question, which may not be measured in the survey.

Designing surveys and using survey results represent a tradeoff. The more specific the questions on the survey to the improvement being analyzed, the more accurate the results. On the other hand, the survey will be less applicable in different situations, and if a different improvement is to be analyzed, new survey efforts may be required.

Usage in Decision-Making:

No information is available.

Ability to Incorporate Changes:

See "Applicability to Diverse Conditions."

Ease-of-Use:

Varies depending on survey type.

3.0 Bibliography

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Antonakos, Cathy L., *Nonmotor Travel in the 1990 Nationwide Personal Transportation* Survey. Transportation Research Record 1502, 1995.	Analysis of NETS data to contrast the characteristics of travelers and of trip characteristics by non-motorized vs. motorized modes (i.e., distribution of trip purposes by mode; distribution of income categories by mode; etc.)
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Aultman-Hall, Lisa, Fred L. Hall and Brian B. Baetz. *Analysis of Bicycle Commuter Routes Using GIS - Implications for Bicycle Planning.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #970168, January 1997.	This analysis makes use of a GIS network data base to determine the characteristics of 397 routes used by commuter cyclists in Guelph, Ontario, and to compare them to the shortest path routes between each origin and destination. The analysis provides useful insight for understanding factors affecting travel behavior such **as** grades, intersections, etc. The study recommends different priorities for improving conditions for existing cyclists and for attracting new cyclists to the network.

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Reference	Description
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Betz, Joe; Jim Dustrude; and Jill Walker. *Intelligent Bicycle Routing in the United States.* Transportation Research Record 1405, 1994.	Discusses the use of Intelligent Transportation System (ITS) technology for bicycle routing.
Botma, Hein. *Method to Determine Level of' Service for Bicycle Paths and Pedestrian-Bicycle Paths.* Transportation Research Record 1502, 1995.	Describes Level of Service (LOS) measures for pedestrians and bicyclists on shared paths. LOS is based on the perceived hindrance to users, as a function of volumes of both types of users, path width, and speeds.
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Burgess, Bruce; Bruce Landis, and Michael Beltz, *NFTC Regional Bikeway Implementation Plan*. Prepared by the Bicycle Federation of America for the Niagara Frontier Transportation Committee, Buffalo, NY, 1998.	This study uses the Bicycle Level of Service (BLOS) to rate roadway conditions for 800 miles of roads in the Buffalo, NY area. Through public involvement and consultant recommendations, target levels of accommodation were designated: minimum LOS C for all links and LOS B for certain priority routes and where opportunities exist.
Caldwell, Erin. *Modal Shift in the Boulder Valley: 1990 to 1996*. City of Boulder, Center for Policy and Program Analysis, March 1997.	Analysis of changes in travel patterns in the Boulder Valley area based on biennial household travel surveys conducted between 1990 and 1996. Purpose is to assess 1989 Transportation Master Plan's objectives of progressively decreasing SOV use. Data suggest that initial goals have been exceeded but that decrease in SOV use has leveled off. (Bicycle and pedestrian mode splits are analyzed but changes are not statistically significant.)
Cambridge Systematics and Barton Aschman Associates. *Travel Survey Manual*. Prepared for U.S. Department of Transportation and U.S. Environmental Protection Agency, 1996.	A guide to conducting household and other types of travel surveys that are used in the development of travel demand forecasting models.
Cambridge Systematics, Inc. *Modeling Non-Motorized Travel* (Work Plan). Cambridge, MA; unpublished draft prepared for Federal Highway Administration, 1996.	Sets forth research and development priorities for incorporating non-motorized travel in travel demand modeling efforts.
Cambridge Systematics, Inc. *Short-Term Travel Model Improvements, Travel Model Improvement Program*. U.S. Department of Transportation; DOT-T-95-05, October 1994. (1994a)	Recommends short-term improvements to travel models. Discussion of non-motorized travel includes an overview of non-motorized environment factors and mode choice in the Portland, OR, and Montgomery Co., MD, travel models, as well as issues associated with modeling non-motorized travel.
Cambridge Systematics. *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior*. Prepared for the Travel Model Improvement Program, U.S. Department of Transportation; DOT-T-95-06, October 1994. (1994b)	Using site surveys and statistical analysis, examines relationships between site design variables, Travel Demand Management measures, and commuter mode choice at a variety of workplaces in Southern California.

Reference	Description
Center for Research and Contract Standardization in Civil Engineering - The Netherlands, Sign *up for* the Bike: Design *Manual for a Cycle-friendly Infrastructure.* Bicycle Master Plan, record 10, The Netherlands, ISBN 90-6628-158-8, September 1994.	*Sign up for the Bike* is a thorough design manual for creating an infrastructure conducive to use of the bicycle. The report first presents the design requirements necessitated by cyclists and then explores various ways those needs can be met through traffic and urban infrastructure planning.
Cervero, Robert and Roger Gorham. *Commuting in Transit Versus Automobile Neighborhoods.* Journal of the American Planning Association, Vol. 61, No. 2, Spring 1995.	This study compares travel behavior (including non-motorized mode split and trip generation rates) in "transit"- vs. "auto"-oriented neighborhoods in the San Francisco and Los Angeles areas. Transit and auto neighborhoods are selected in matched pairs to control for density, income, etc. Transit and non-motorized trip rates and mode shares are higher in the "transit" neighborhoods.
Chesapeake Bay Foundation, Environmental Defense Fund, et al. *A Network of Livable Communities: Evaluating Travel Behavior Effects of Alternative Transportation and Community Designs for the National Capital Region.* Washington, DC, May 1996.	Describes how non-motorized travel and influencing factors are included in travel modeling to analyze alternative development scenarios. The PROMO (Proximity Mode Choice Model) is a pivot-point logit sketch model which interacts with the official Metro Washington model to evaluate the effects of pedestrian and bicycle friendliness strategies on travel behavior.
City of Portland, OR, Office of Transportation. *Identifying Priorities for Pedestrian Transportation Improvements.* Pedestrian Master Plan Project Development: Final Report, June 30, 1997.	Describes the development of two indices to aid in prioritizing pedestrian projects: the Pedestrian Potential Index and Deficiency Index. The Pedestrian Potential Index highlights the locations where pedestrian activity is likely to be greatest, based on land use and pedestrian environment conditions. The Deficiency Index rates the quality of existing pedestrian infrastructure to identify areas which are most deficient.

Reference	Description
Clark, David E. *Estimating Future Bicycle and Pedestrian Trips* From *A Travel Demand Forecasting Model.*, Institute of Transportation Engineers, 67th Annual Meeting, 1997.	Describes a process to adjust vehicle trip tables in a travel demand model to account for future increases in bicycle and pedestrian trips. Existing trips are stratified by length and purpose, and adjustment factors which represent a potential percent increase in bicycle and pedestrian trips as a result of future improvements to the bicycle and pedestrian network are applied to reduce the number of vehicle trips. The adjustment factors vary by trip purpose, length, and mode and are based on local judgment.
Clarke, Andy. *Bicycle-Friendly Cities: Key Ingredients for* Success. Transportation Research Record 1372, 1995.	Describes key factors that lead to high levels of bicycling in certain cities.
Cynecki, M.J., G. Perry, and G. Frangos. *Study of Bicyclist Characteristics in Phoenix, Arizona.* Transportation Research Record 1405, 1993.	Describes characteristics of bicyclists in the Phoenix area based on local surveys.
Davies, D.G., M.E. Halliday, M. Mayes, and R.L. Pocock. *Attitudes to Cycling: A Qualitative Study and Conceptual Framework.* TRL Report 266: Transport Research Laboratory, Crowthorne, Berkshire (UK), 1997.	Examines attitudes towards cycling and factors which would influence people to cycle, based on interviews, focus groups, and stated-preference surveys. Introduces a conceptual framework for promoting cycling based on concepts from the public health and social marketing fields, which focus on identifying and changing behavior in stages. Also includes a review of previous attitudinal studies in the UK.
Davis, Scott E., L. Ellis King and H. Douglas Robertson. *Predicting Pedestrian Crosswalk Volumes.* Transportation Research Record 1168, 1991.	The authors describe a method to measure and predict pedestrian crosswalk volumes for the evaluation of traffic signal requests and for the compilation of hazard indices data. The method uses short-term counts of five to 10 minutes and is more cost effective than performing continuous counts.
Deakin, Elizabeth A. *Utilitarian Cycling: A Case Study of the Bay Area and Assessment of the Market for Commute Cycling.* University of California, Berkeley, ITS Research Report, 1985.	The author defines a demographic target group for San Francisco Bay Area commuter cycling, based on data from the Bay Area Travel Survey, a review of the literature, and interviews with local and state officials. Her market is defined as: employed full-time; under 40 years old; travel less than 11.2 km one-way to work; drives alone during the peak-period; and owns a bike suitable for commuting. She then uses these criteria to estimate a reasonable upper bound on the size of the potential bicycle commuter market.

Reference	Description
Demetsky, Michael J. and David Morris. *Structuring an Analysis of Pedestrian Travel.* Highway Research Record **467, 1973.**	Sets forth a framework for analyzing the demand for pedestrian travel. This demand is hypothesized as a function of four factors: functional class of the trip, trip characteristics, characteristics of the trip maker, and quality of the walking environment. Desired data include relative preferences for accommodations (by type of pedestrian) as determined by attitudinal surveys; existing data on walking behavior in different environments; and field evaluations of walking environments.
Department of Transport. *Traffic Advisory Leaflet 8/95: Traffic Models for Cycling.* London, UK, 1995.	Overview of application of QUOVADIS-BICYCLE to Ipswich, UK.
DeRobertis, Michelle and Alan Wachtel. *Traffic Calming: Do's and Don'ts to Encourage Bicycling.* 1996 Compendium of Technical Papers, Institute of Transportation Engineers 66th Annual Meeting, pp. **498-502, 1996.**	Discusses the compatibility of various traffic calming measures with bicycling and recommends approaches to implementing traffic calming in a bicycle-friendly manner.
DHV Environment and Infrastructure. *QUOVADZS-BICYCLE User's Manual.* Amersfoort, Netherlands (no date).	Documentation for the QUOVADIS-BICYCLE network model.
Dillman, D. *Mail and Telephone Surveys: The Total Design Method.* Wiley-Interscience: New York, 1978.	While somewhat dated, a generally excellent resource for anyone interested in designing and conducting an attitudinal survey of existing or potential bicyclists and pedestrians.
Dixon, Linda. *Adopting Corridor-Specific Performance* Measures *for Bicycle and Pedestrian Level of Service.* Transportation Planning, city of Gainesville, Fla. Traffic Engineering Department, pp. 5-7, summer 1995.	Describes the development and application of bicycle and pedestrian level of service measures in Gainesville, FL.
Eddy, Nils. *Developing a Level of Service for Bicycle Use*, Pro Bike Pro Walk 96: Forecasting the Future, Bicycle Federation of America/Pedestrian Federation of America, pp. 310-314, September 1996.	Describes the development of a bicycle level of service measure to rate the suitability of roadway facilities for bicycling.

Reference	Description
Epperson, Bruce. *Bicycle Transportation Planning: A Quantitative Approach*, DRAFT, pp. l-42, January 15, 1996.	Includes, among other items, a discussion of the traditional travel demand forecasting process and its possibilities and limitations with respect to bicyclists; a literature review of existing quantitative approaches to bicycle travel; and potential future developments for modeling of bicycle travel.
Epperson, Bruce. *Demographic and Economic Characteristics of Bicyclists Involved in Bicycle-Motor Vehicle Accidents.* Transportation Research Record 1502, 1995.	Examines demographic and economic characteristics of bicyclists involved in bicycle-motor vehicle accidents. Accidents are regressed against census tract characteristics to predict total and per-capita accidents and to identify factors associated with accident risk.
Epperson, Bruce. *Evaluating Suitability of Roadways for Bicycle Use: Toward a Cycling Level-of-Service Standard.* Transportation Research Record 1438, 1994.	Reviews recent work to determine Level of Service indicators for bicyclists and discusses factors to be considered in future refinement of such indicators.
Epperson, Bruce. *On the Development of a Roadway Level of Service Standard For Bicycles: A Histo y and Discussion.* Miami Urbanized Area Metropolitan Planning Organization, 1994.	See Epperson (Transportation Research Record, 1994).
Epperson, Bruce, Sara J. Hendricks, and Mitchell York. *Estimation of Bicycle Transportation Demand from Limited Data.* University of South Florida (no date).	Attempts to predict bicycle travel based on four types of available data: (1) accident rates; (2) census data - Category 1 Transportation Disabled population; (3) census data - bicycle work trip percentage; and (4) bicycle trip rates as a function of demographic data, based on the 1990 NPTS. Predictions from the four methods do not correlate well. However, bicycle counts and analysis in five neighborhoods suggest that simplified methods can be reasonably predictive if (1) they are combined with specific information about an area's geography and demographics, and (2) recreational and utilitarian trip-making are differentiated.
Ercolano, James M., Jeffrey S. Olson, and Douglas M. Spring. *Sketch-Plan Method for Estimating Pedestrian Traffic for Central Business Districts and Suburban Growth Corridors. New* York State Department of Transportation; in Transportation Research Record 1578, 1997.	Presents a sketch-plan method for estimating pedestrian traffic at intersections and mid-block locations of commercial areas. The method applies access-egress mode trip generation and applies peak vehicle per hour turning movements, transit vehicle or passenger counts, and walk/bike counts or projections to produce peak pedestrian-per-hour trips.

Reference	Description
Erickson, Michael. ***The Potential for Bicycle Transportation in Chicagoland.*** Proceeds of *the Velo 1992* conference *(Perspectives **Mondiales** Sur **le Velo;*** The Bicycle: Global Perspectives,) 1992.	Estimates the potential market for bicycle commuting in Chicago, based **on** demographic data and data on trip characteristics from travel surveys. Uses market potential analysis techniques based on Deakin (1985).
Evans, John E., IV, Vijay **Perincherry,** and G. Bruce Douglas, III. *Transit Friendliness Factor: An Approach to Quantifying the Transit Access Environment in a Transportation Planning Model.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper **#971435,** January 1997.	Describes the development of a "transit friendliness factor" to indicate the quality of the environment for pedestrian access to transit **stations.**
Federal Highway Administration (Stewart **A.** Goldsmith). Case Study No. ***1:*** *Reasons Why Bicycling and Walking Are Not Being Used* More *Extensively As Travel* Modes. National Bicycling and Walking Study, U.S. Department of Transportation (FHWA), Publication No. FHWA-I'D-92-041,1992.	Includes a literature review and interpretation of (1) factors influencing individual choices to bike or walk; (2) aggregate levels of bicycling and walking based on area characteristics; (3) **non-**motorized data collection efforts; and (4) analytic methods for determining non-motorized transportation demand.
Federal Highway Administration. *A Compendium* **of** *Available Bicycle and Pedestrian Trip Generation Data in the United States, A Supplement to the* National *Bicycling and Walking Study.* U.S. Department of Transportation (FHWA), October 1994.	Reviews bicycle and pedestrian counts and mode choice studies in a number of communities and on a variety of facility types. Information was gathered by reviewing selected literature and contacting individuals in U.S. communities known to have active bicyclist and pedestrian programs.
Federal Highway Administration. *Selecting Roadway Design Treatments to Accommodate **Bicycles.*** U.S. Department of Transportation, FHWA, Turner-Fairbank Highway Research Center: McLean, VA, January 1994.	Provides guidance to assist transportation planners and engineers in selecting roadway design treatments to accommodate bicycles.

Reference	**Description**
Federal Highway Administration. *Development of the Bicycle Compatibility Index: A Level of Service Concept* (Final Report). U.S. Department of Transportation, FHWA, Turner-Fairbank Highway Research Center: McLean, VA, Publication No. FHWA-RD-98-072, August 1998.	This paper seeks to establish a methodology to determine how compatible a roadway is for allowing the efficient operation of both bicycles and motor vehicles. The authors develop a method for evaluating urban and suburban roadway segments via the use of their Bicycle Compatibility Index (BCI). The BCI seeks to assess those variables used by cyclists to determine the "bicycle friendliness" of a roadway by measuring the geometric and operational characteristics of a variety of roadways. Specifically, the BCI is determined based on an equation which includes various factors pertaining to the space available for the cyclist and the characteristics (volume, vehicle size, etc.) of the roadway. Ultimately, this index could be used to evaluate and design bicycle routes.
Frank, Lawrence D. *An Analysis of Relationships Between Urban Form (Density, Mix, and Jobs: Housing Balance) and Travel Behavior (Mode Choice, Trip Generation, Trip Length, and Travel Time).* Washington State Department of Transportation, Olympia, WA, 1994.	See Frank et al (1997).
Frank, Lawrence D.; Brian Stone, Jr. and Eric Matthew Pihl. *A Methodology to Measure Land Use Relationships With Travel Behavior and Vehicle Emissions.* DRAFT, July 1997.	For the Puget Sound area, trip generation by mode, travel time and distance, and modal choice (including non-motorized) per household are related using regression analysis of tract-level land use variables (density, mix, and pedestrian connectivity), transit level of service, and household demographic variables. Data are taken from a regional travel survey, a land use database, and the census.
Garder, Per. *Rumble Strips or Not Along Wide Shoulder-s Designated for Bicycle Traffic?* Transportation Research Record 1502, 1995.	Discusses the use of rumble strips to alert inattentive drivers who stray from the traffic lane and onto wide shoulders used by bicyclists.
Goldsmith, Stuart. *Estimating the Effect of Bicycle Facilities on VMT and Emissions.* **DRAFT,** Seattle Engineering Department (no date).	Describes the development and application of a sketch-plan method to estimate the number of users of a bicycle facility under development, and to estimate the impact of the facility on reducing motor-vehicle miles traveled and emissions.

Reference	Description
Handy, Susan. *Urban Form and Pedestrian Choices: Study of Austin Neighborhoods.* Transportation Research Record 1552, 1996.	Explores the relationships between urban form (traditional, early modern, or late modern neighborhood) and the choice to make pedestrian trips. Based on a study of six neighborhoods in Austin, TX, examines correlation between personal, attitudinal, and environment factors and the propensity to walk for recreation or for shopping. The data suggest that certain aspects of urban form can play an important role in encouraging walks to a destination but that the savings in travel from the substitution of walking for driving is likely to be small.
Harkey, David L., and J. Richard Stewart. *Evaluation of Shared-Use Facilities* for *Bicycle and Motor Vehicles.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #970840, January 1997.	Evaluates the safety and utility of shared-use bicycle facilities based on observations of bicyclists and motorists interacting on different types of roadways.
Hass, R.C.G. and J.F. Morrall. *Circulation Through a Tunnel Network.* Traffic Quarterly, April 1967.	Describes a survey of pedestrian tunnels between all major buildings and parking lots of Carleton University in Ottawa, Canada. The objective was to develop a pedestrian demand model for future design criteria. Data were collected using an origin-destination questionnaire survey, and the model was calibrated using screen-line counts and walking time-distance surveys. Trips were assigned to a network system by a computer assignment program based on results of the survey. (Referenced in Behnam and Patel, 1977)
Hoekwater, J. Cycle *Routes in the Hague* and *Tilburg.* Published in Cycling as a Mode of Transport: Proceedings of a Symposium held at the Transport and Road Research Laboratory, Crowthorne, U.K. (TRRL Supplementary Report 540), October 1978.	Documents a study comparing cycle traffic before and after the addition of cycle lanes in the Netherlands. Counts are also performed on parallel facilities to attempt to estimate diversion vs. new riders. In one location, cycle counts increased by 30 to 60 percent on the route with a slight increase on parallel routes. For a different location, cycle traffic on the route also increases but there is some decrease on parallel facilities; the authors conclude that roughly two-thirds of the increase in cycle traffic comes from parallel routes and one-third from new trips.

Reference	Description
Hopkinson, P. and M. Wardman. *Evaluating the Demand for New Cycle Facilities.* Transport Policy Vol. 3, 1996.	Stated-preference techniques are used to obtain valuations of improvements to cycle facilities, forecast the effects of such facilities on route choice, and provide a partial cost-benefit analysis of alternate cycle routes.
Horowitz, Mark. *Overview of Three Roadway Condition Indexing Models for Bicycle Transportation.* Pro Bike Pro Walk 96: Forecasting the Future, Bicycle Federation of America/Pedestrian Federation of America, pp. 303-309, September 1996.	Describes and compares the pros and cons of three. roadway compatibility measures for bicyclists: the Roadway Condition Index developed by Davis (1987), the Bicycle Stress Level developed by Sorton and Walsh (1994), and the Interaction Hazard Score developed by Landis (1996).
Hsaio, Shirley. *Using GIS for Transit Pedestrian Access Analysis.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #970157, January 1997.	This study uses GIS techniques to analyze pedestrian accessibility to transit in Orange County, CA, using the actual street network and population information by Census Tract. Among other things, the technique can be used to estimate the impacts on catchment population (and potentially mode choice) of improvements to the pedestrian network.
Huang, Yuanlin. *A Multimodal Simultaneous Equilibrium Travel Forecasting Model for Congested Urban Areas.* Maryland-National Capital Park and Planning Commission, Silver Spring, MD (no date).	Describes the development of **a** travel model for Montgomery County, MD. The model includes zone-level indices of bicycle and pedestrian friendliness.
Huang, Yuanlin. *Selecting Bicycle Commuting* Routes *Using GIS.* Berkeley Planning Journal 10, U.C. Berkeley, pp. 75-90, 1995.	Describes the application of GIS techniques to planning bicycle routes.
Hunt, J.D. and J.E. Abraham. *Influences on* Bicycle Use. Submitted for presentation at the 1998 Transportation Research Board Annual Meeting, July 1997.	A discrete route choice model was developed based on a hypothetical-choice stated-preference survey of cyclists in Edmonton, Canada. Facility factors included time spent cycling on three different facility types and the availability of showers and secure bicycle parking. Socioeconomic data and indicators of experience and comfort level were also used in model development.

Reference	Description
Hunt, J.D., A.T. Brownlee, and L.P. Doblanko. Design and *Calibration of the Edmonton Transport Analysis Model.* Presented at the 1998 Transportation Research Board Annual Meeting, Paper #981076, January 1998.	Describes a travel model for the Edmonton, Canada region which includes bicycle and walk as mode choices. Bicycle mode choice uses a "bicycle equivalent travel time" which weights travel time by facility type (bike path, bike lane, or mixed traffic) based on results of a stated-preference survey (Hunt and Abraham, 1997). The model uses aggregate nested logit models at each step (generation, destination, time of day, and mode choice) and feeds composite utilities from each step to the previous step.
Hunter, William W. and Herman F. Huang. *User Counts on Bicycle Lanes and Multi-Use Trails* in *the United States.* Transportation Research Record 1502, 1995.	Examines temporal patterns in the number of bicycle trips along bicycle lanes and trails, at various locations throughout the United States.
Hyodo, Tetsuro; Norikazu Suzuki and Yoji Takahashi. *Modeling Bicycle Route Choice Behavior on Describing Bicycle Road Network in Urban Area.* Presented at the 1998 Transportation Research Board Annual Meeting, Paper #980353, January 1998.	Proposes a bicycle route choice model in which facility characteristics (e.g., road width or sidewalk) affect the impedance function in route choice. Development of the model is based on a survey of bicyclists in which they are asked to map their trip on a network. Parameters are estimated based on actual versus minimum-path routes, using the Genetic Algorithm method.
Jack, William. *Using GIS to Address Pedestrian* Issues. City of Seattle; Presented at the 1997 National Pedestrian Conference, Washington, DC, September 1997.	The City of Seattle has created inventories of its pedestrian facilities using GIS. This information is being matched to locations of elementary schools, neighborhood service, and neighborhood business districts to prioritize pedestrian facility improvements.
Jager, Joke and Mark Gommers. *Innovative Approaches to Regional Traffic Forecasting Models in the Netherlands.* ITE 1993 Compendium of Technical Papers, ITE; Dutch Ministry of Transport, pp. 244-247, 1993.	Provides an overview of the Dutch Regional traffic forecasting Model System (RMS). Walk/cycle mode choice is included in the model, but the method of incorporation is not described here.
Kagan, L.S., W.G. Scott, and U.P. Avin. *A Pedestrian Planning Procedures Manual.* Prepared for the Federal, Highway Administration, Report Nos. FHWA-RD-79-45, FHWA-RD-79-46, and FHWA-RD-79-47 (3 Volumes), 1978.	This manual outlines a formal Pedestrian Planning Process (PPP), including a demand modeling phase and a design and evaluation phase. The PPP includes a comprehensive evaluation of existing and forecast pedestrian travel patterns and movement requirements. Demand modeling procedures are similar to standard transportation modeling procedures and include trip generation, trip distribution, and traffic assignment.

Reference	Description
Katz, Rod. *Demand for* Bicycle Use: *A Behavioral Framework and Empirical Analysis for Urban NSW*, Doctoral Thesis, The Graduate School of Business, The University of Sydney, Sydney, NSW, Australia, December 1996.	Demand for commuter bicycle use is modeled in two steps: (1) the choice to participate (bicycle) is modeled (through factor analysis and logit regression) based on attitudes and personal characteristics; and (2) mode choice is modeled through discrete choice (logit) models which include attitudes, personal characteristics, and structural factors (cost, distance, etc.). Bicycle facility measures include bicycle cost, trip distance, availability of showers and parking at the trip end, and percent of trip on a bike path. Elasticities for the bicycle mode are -0.88 for trip distance, +0.58 for percent of trip on bike path, and +0.26 for car cost. Inclusion of attitudinal factors is found to significantly improve model fit. Data are based on telephone and in-person surveys and choice experiments. An extensive discussion and literature review of the behavior modeling issues and techniques relevant to bicycle travel modeling is also included.
Katz, Rod. *Modeling Bicycle Demand as a Mainstream Transportation Planning Function.* Transportation Research Record 1502, 1995.	Reviews current quantitative techniques for modeling bicycle travel; argues for greater consideration of bicycle travel in formal transportation planning models.
Khan A. M., and A. Bacchus. *Bicycle Use of Highway Shoulders.* Transportation Research Record 1502, 1995.	Describes recent research on opportunities and issues in the use of highway shoulders for bicycle routes, including design factors and safety and economic benefits.
Kines, Chuck. *Evaluating Community Livability Using a Core Set of Bicycle and Pedestrian Facilities as Indicators,* Draft Report, University of Maryland, August 1997.	Advocates and establishes a framework for developing a set of bicycle and pedestrian facility indicators which can be used to evaluate community livability.
Kitamura, Ryuichi, Patricia L. Mokhtarian, and Laura Laidet. *A Micro-Analysis of Land Use and Travel in Five Neighborhoods in the Sun Francisco Bay Area.* Transportation Vol. 24 No. 2, May 1997.	The authors conduct stated-preference surveys to determine the relative influence of socioeconomic, attitudinal, and neighborhood characteristics on travel behavior. Discrete choice models are developed to predict mode choice and total number of **trips by mode.** Facility **variables include** presence of sidewalks and bike paths as well as perceptions of whether streets are pleasant for walking or cycling.
Klosterman, Richard, *TIGER: A Primer for Planners.* Planning Advisory Service Report Number 436, American Planning Association, Chicago, Illinois, 1991.	Guidance on the use of Census TIGER files.

Reference	Description
Kockelman, Kara Maria. *Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidencefrom the* San *Francisco Buy Area.* Master's Thesis, Department of City and Regional Planning, University of California at Berkeley, 1996.	Relates vehicle miles of travel (VMT), auto ownership, and mode choice to various land use descriptors, accessibility measures, and socioeconomic characteristics at the census tract level, based on Bay Area data. Includes an aggregate walk/bike mode choice model (no facility descriptors). GIS is used extensively for data analysis.
Kocur, George; William Hyman and Bruce Aunet. *Wisconsin Work Mode-Choice Models Based on Functional Measurement and Disaggregate Behavioral Data.* Transportation Research Record 895, 1982.	Work-trip logit mode choice models are developed for four sets of metropolitan areas in Wisconsin based on the results of stated and revealed-preference surveys. Bicycle and walk are included as separate mode choices. Bicycle facility variables include distance to work, lane (yes or no), street surface (smooth or rough), and traffic (busy or quiet). Pedestrian facility variables include distance to work, presence of sidewalks, and season (summer or winter).
Landis, Bruce W. *Bicycle Interaction Hazard Score: A Theoretical Model.* Transportation Research Record 1438, 1994.	Describes a theoretical model to estimate bicyclists' perception of the hazards of sharing roadway segments with motor vehicles.
Landis, Bruce W. *Bicycle System Performance Measures.* ITE Journal, February 1996.	Describes how the Interaction Hazard Score and Latent Demand Score developed by the author can be used to evaluate, test, and prioritize on-road bicycle projects.
Landis, Bruce W. *NFTC Regional Bikeway Implementation Plan: Scoring Methodology Report*, Sprinkle Consulting Engineers, Inc., Tampa, FL, March 1997.	Describes the application of the Bicycle Level of Service to rate the quality for bicycling of existing streets in the Buffalo, NY, area.
Landis, Bruce W. and Venkat R. Vattikuti. *Real-Time Human Perceptions: Toward a Bicycle Level of Service.* Sprinkle Consulting Engineers, Inc., September 1996.	Describes the development of a Bicycle Level of Service (BLOS) based on earlier work to develop an Interaction Hazard Score and new research.
Landis, Bruce, and Jennifer Toole. *Using the Latent Demand Score Model to Estimate Use.* Pro Bike Pro Walk 96: Forecasting the Future, Bicycle Federation of America/Pedestrian Federation of America, pp. 320-325, September 1996.	Describes an application of the Latent Demand Score.

Reference	Description
Lewis, Cathy Buckley and James E. Kirk, *Central Massachusetts Rail Trail Feasibility Study,* Central Transportation Planning Staff, Boston, MA, April 1997.	An existing bicycle/pedestrian facility and its surrounding population are compared with a proposed facility and its surrounding population to estimate potential usage levels on the proposed facility.
Louisse, *Cees* J. *Obstacles and Potentions (sic) for Replacing Car Trips by Bicycle Trips.* Proceeds of the *Velo* 1992 conference *(Perspectives Mondiales Sur le Velo; The* Bicycle: Global Perspectives), 1992.	Conducts a survey in the Netherlands asking people about obstacles to bicycling and willingness to change behavior. Respondents are asked to record all car trips for a week, and to note whether the trip could have been made by bicycle (impossible, only with much trouble, or possible). These estimates are used to develop a range of potential mode shift from car to bicycle. Different impediments are identified for trips of each degree of replaceability.
Loutzenheiser, David R. *Pedestrian Access to Transit: A Model of Walk Trips and their Design and Urban Form Determinants Around BART Stations.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #971424, January 1997.	A discrete choice model of transit mode choice access is developed based on passenger surveys and station area characteristics for the Bay Area Rapid Transit system (BART) in San Francisco. Urban design and station area characteristics are found to be secondary to individual characteristics in determining the choice to walk. (Station area variables include nearby arterials and freeways; grid pattern; population density; and type and mix of land uses. Descriptors are developed using GIS techniques.)
Maptitude Overview (http://www.caliper.com), Caliper Corporation.	Reviews the capabilities of Maptitude GIS software.
Matlick, Julie Mercer. *If We Build it, Will They Come? (Forecasting Ped. Use and Flows).* Pro Bike **Pro** Walk 96: Forecasting the Future, Bicycle Federation of America/Pedestrian Federation of America, pp. 315-319, September 1996.	Potential pedestrian trips in a corridor are estimated using existing land use and mode split **data and estimates** of **pedestrian** trips from various types of trip generators (land uses, transit, etc.) The method is used for prioritizing corridors/locations for pedestrian improvements.

Reference	Description
Mescher, Phillip J. and Reginald R. Souleyrette. Use *of an Internet-Based Delphi Technique and Geographic Information System for Bicycle Facility Planning.* Paper written for the 1996 Geographic Information Systems for Transportation Symposium, 1996.	The authors use a GIS to assign bicycle condition index (BCI) values to the city street network of Ames, Iowa. The BCI was developed using the Delphi technique, using the intemet to coordinate expert panelist responses. The authors then develop an optimal route-planning tool, using a shortest-path FORTRAN algorithm, that minimizes the sum of (negative) link scores between two identified nodes. The outputs of the optimal route calculations are then compared to existing bicycle routes.
Metropolitan Transportation Commission. *San Francisco Bay Area 1990 Travel Model Development Project: Compilation of Technical Memoranda* (Volumes II-VI). Oakland, CA, 1995-1997.	Describes the development of the various trip generation, trip distribution, and mode choice models which are used in the San Francisco Bay Area travel models. The current status and history of Bay Area modeling efforts are also described, and Volume VI includes a description of current home-based work trip mode choice models developed by other MPOs which include non-motorized travel.
Meyer, Michael D. *A Toolbox for Alleviating Traffic Congestion.* Institute of Transportation Engineers; Prepared for the Federal Highway Administration, Washington, DC, 1997.	Contains some basic information and references on bicycle trip characteristics, benefits and costs, and implementation guidelines for bicycling as a Transportation Demand Management (TDM) strategy.
Milam, Ronald T. and Michael G. Jones. *Engineering A Bikeway Master Plan.* Fehr & Peers Associates, Inc., Prepared for the 1995 ITE District 6 Annual Meeting, Denver, Colorado, August 9, 1995.	Methods and issues to consider in developing a bicycle master plan.
Montgomery County Planning Department. *Travel/2: A Simultaneous Approach to Transportation Modeling (Draft).* Montgomery County, MD, February 1993.	Describes the development of a travel model for Montgomery County, MD. The model includes zone-level indices of bicycle and pedestrian friendliness.
Moritz, William E. *A Survey of North American Bicycle Commuters – Design and Aggregate Results.* University of Washington; Presented at the 1997 Transportation Research Board Annual Meeting, Paper #970979, January 1997.	Documents a survey of 2,374 bicycle commuters in the United States and Canada. Includes socioeconomic and demographic information, commuting habits/trip characteristics, accidents, equipment and facilities used, “relative danger” by type of street, and motivation.

Reference	Description
Moudon, Anne Vernez, Paul Hess, Mary-Catherine Snyder, and Kiril Stanilov. *Effects of Site Design on Pedestrian* Travel *in Mixed-Use, Medium-Density Environments.* Presented at the 1997 Transportation Research Board Annual Meeting, Paper #971360, January 1997.	This paper tests the hypothesis that pedestrian network connectivity is an important factor in determining pedestrian activity levels. Selecting 12 sites in the Puget Sound area to control for population density, income, and land use mix, intensity, and distribution, the study finds that areas with direct pathways and a complete system of pedestrian facilities have significantly higher rates of pedestrian travel (as measured by counts).
Mozer, David. *Calculating Multi-Mode Levels-of-Service,* (abridged). International Bicycle Fund, http://www.halcyon.com/fkroger/bike/los.htm, August 1997.	Describes the development of a level-of-service (LOS) measure referred to as "Pedestrian, Bicycle, Auto, Transit Level of Access" (P-BAT LOA). The purpose is to establish a multimodal level of service measure as an alternative to traditional LOS measures, which do not consider bicycle, pedestrian or transit modes.
WA, *Leicester Cycle Model Study,* Final Report, prepared for Leicestershire County Council, Contract No. 02/C/1428, October 1995.	Describes the development and application of a cycle network model for the Leicester, England area. The model distributes future cycle trips given a network of existing and proposed roads and cycle facilities. Cycle trip tables are developed based on existing trip tables for motorized travel in conjunction with cycle trip length distributions. The model does not forecast future levels of cycling, but rather uses an assumed level of future cycle traffic under ideal conditions and distributes it to a future-year network.
Nelson, Arthur C., and David Allen. *If You Build Them, Commuters Will Use Them: Cross-Sectional Analysis of Commuters and Bicycle Facilities.* City Planning Program, Georgia Institute of Technology; Presented at the 1997 Transportation Research Board Annual Meeting, Paper #970132, January 1997.	Cross-sectional analysis of 18 U.S. cities to predict work trip bicycle mode split (census data) based on weather, terrain, number of college students, and per capita miles of bikeway facilities. A positive association is found.

Reference	Description
Ness, M.P., J.F. Morrall, and B.G. Hutchinson. *An Analysis of Central Business District Pedestrian Circulation Patterns.* Highway Research Record 283, 1969.	This study applies the gravity model technique to forecast pedestrian volumes in the Toronto area. The CBD is divided into office zones, linked by pedestrian facilities. Trip generation rates are measured for office zones and transportation terminals, and are used in conjunction with a set of friction factors and minimum-path walking trees as inputs to a gravity-type distribution model. The minimum path is calibrated on the basis of walking time, waiting time at intersections, street attractiveness, and a turn penalty. (Referenced in Behnam and Patel, 1977)
Niemeier, D.A. and G.S. Rutherford. *Non-Motorized Transportation, 1990* NPTS *Special Report.* Report FHWA-PL-94-019, FHWA, U.S. Department of Transportation, 1994.	Evaluates bicycle and pedestrian trip characteristics and demographic characteristics of travelers in the 1990 National Personal Transportation Survey.
Niemeier, Debbie. *Longitudinal Analysis of Bicycle Count Variability: Results and Modeling Implications.* ASCE Journal of Transportation Engineering, American Society of Civil Engineers, May/ June 1996.	Describes efforts to count bicycle traffic volumes; discusses issues which may affect counts, such as commuter vs. recreational bicycling patterns and the effects of weather.
Noland, Robert B. *Perceived Risk and Modal Choice: Risk Compensation in Transportation* Systems. Accident Analysis and Prevention, Vol. 27 No. 4, 1995.	See Noland and Kunreuther, 1995 (same study, greater focus on safety aspects).
Noland, Robert B. and Howard Kunreuther. *Short-Run and Long-Run Policies for Increasing Bicycle Transportation for Daily Commuter Trips.* Transport Policy, Vol. 2 No. 1, 1995.	Multinomial logit models are developed which relate use of a mode to perceptions of risk and convenience of that mode (perceptions of cost, comfort, and relevant personal variables are also included). Modes include auto, transit, bicycle, and walk. Risk and convenience perceptions are measured based on surveys of bicyclists and of the general population. The model is used to evaluate the general effect of policy variables on mode split. Elasticities are developed with respect to bicycle convenience, comfort, parking availability, competency, and lack of shoulders, as well as auto cost, convenience, and comfort. "Short-run" and "long-run" elasticities and mode splits are developed, which assume that many people do not have a choice of modes in the short run, but that in the long run different urban form policies and residential location decisions could allow everyone a choice of modes.

Reference	Description
Northwestern University Traffic Institute. *Pedestrian and Bicycle Considerations in Urban Areas - An Overview*. Training course developed for the U.S. Department of Transportation, Federal Highway Administration, in cooperation with Barton-Aschman Associates. (no date; est. late 1970s).	Outlines a sketch-planning approach to estimating potential bicycle trips based on population, employment, school trip activity, and other factors. Approach appears similar to that used by Ohm (1976), who was also with Barton-Aschman at the time of his article.
Ohm, Carl E. *Predicting the Type and Volume of Purposeful Bicycle Trips*. Transportation Research Record 570, 1976.	Estimates the potential number of bicycle trips in the Minneapolis-St. Paul area, assuming that adequate facilities are provided, based on existing trip lengths and frequencies by purpose and on estimated maximum diversion by length and purpose, given ideal conditions.
Ortuzar, Juan de Dios, Andres Iacobelli and Claudio Valeze, *Estimating Demand for A Cycleway Network*, Department of Transport Engineering, Pontificia Universidad Catolica de Chile (no date).	A travel survey including stated choice experiments for potential bicyclists was conducted in Santiago, Chile. A logit model is constructed to predict "willingness to cycle" under the assumption of a dense network of segregated cycleways and parking facilities, and a mode choice model is subsequently developed. Based on total trips and travel attributes for each origin-destination (O-D) pair of the regional travel model, the number of potential bicycle trips is estimated for each O-D pair and overall.
Pioneer Valley Planning Commission, *Survey of Users on the Norwottuck Rail Trail*, Federal Highway Administration, July 19, 1996.	Documents a survey of users of the Norwottuck Rail Trail in central MA, including trip, access, and user characteristics.
Public Opinion Research, Inc., *Report on a Telephone Survey Conducted in the Route One Corridor of* New Jersey, February 5, 1997.	This report provides the processed data from a phone **survey** of 500 households along the Route One Corridor in New Jersey. The survey explored the respondents' use of the corridor and their opinions towards infrastructure improvements to make the corridor more bike and pedestrian friendly. Almost three-quarters of respondents replied that they strongly support policies that encourage development supportive of walking and bicycling. This survey was commissioned by the Bicycle Federation of America.

Reference	Description
Pushkarev, Boris and Jeffrey M. Zupan. *Pedestrian Travel Demand.* Highway Research Record 355, 1971.	The authors of this article study the nature of pedestrian flow in the central business district of midtown Manhattan. Their survey analyzed the number and kinds of pedestrians and the nature of their trips, including trip times and distances. Regression analysis is used to relate pedestrian volumes to adjacent land uses. The study provides several methodologies ranging from aerial photography to street-side surveys to collect data.
Replogle, Michael. *Inside the Black Box: An Insider's Guide to Transportation Models.* Pro Bike Pro Walk 96, Bicycle Federation of America/Pedestrian Federation of America, pp. 276-280, September 1996.	Overview of travel modeling for laypersons, including how non-motorized travel can be incorporated.
Replogle, Michael. *Integrating Pedestrian and* Bicycle Factors *into Regional Transportation Planning Models:* Summary of *the State-of-the-Art and Suggested Steps Forward.* Environmental Defense Fund, July 20, 1995.	Summarizes and critiques current non-motorized modeling practices, and suggests future directions.
Ridgway, Matthew D. *Generating Fine Levels of Detail from a Regional Modeling Package.* ITE 1994 Compendium of Technical Papers, ITE; Fehr & Peers Associates, pp. 425-429, 1994.	Discusses how large area traffic network models can be used to generate fine-level details such as intersection turning movements, link-specific zonal contribution estimates, and parcel-level trip allocations.
Ridgway, Matthew D. *Projecting Bicycle Demand: An Application of Travel Demand Modeling Techniques to Bicycles.* 1995 Compendium of Technical Papers, Institute of Transportation Engineers 65th Annual Meeting, pp. 755-785, 1995.	Describes the theoretical development of a bicycle-specific travel model, based on traditional travel modeling principles, and its application to the city of Berkeley, California. Bicycle trips are currently assigned based on travel distances; link attributes could potentially be included. Problems were encountered in predicting bicycle mode split at a Census Tract level based on available data.
Ronkin, Michael. *Surveying Actual Roadway User Characteristics.* Pro Bike Pro Walk 96: Forecasting the Future, Bicycle Federation of America; Pedestrian Federation of America, pp. 307-309, September 1996.	This article argues for the importance of conducting user surveys to accurately assess pedestrian and bicycling conditions and demands. The author shows various ways that traditional methods of counting users may be inexpensively yet productively enhanced. Hard data, Ronkin argues, is essential to making good policy.

Reference	Description
Rossi, Thomas, T. Keith **Lawton** and Kyung Hwa Kim. *Revision of Travel Demand Models to Enable Analysis of Atypical Land Use Patterns.* Cambridge **Systematics,** Inc. and Metropolitan Service District, May 1993.	Describes revision of travel models in the Portland, OR, area to include (among other things) non-motorized mode choice as a function of local land use and environment variables.
Shafizadeh, Kevan and Debbie Niemeier. *Bicycle Journey-to-Work: Travel Behavior Characteristics and Spatial Attributes.* Transportation Research Record **1578, 1997.**	Analyzes characteristics of commuter cyclists, including travel time by income, age, gender, and proximity to bicycle trail, based on surveys of commuters on CBD bike lanes and on the **Burke-Gilman** trail in Seattle.
Sharples, Rosemary. "Think Bike! - TRIPS *Goes Cycling," The MVA Consultancy,* Manchester, TRIPS Software News, August 1996.	See MVA (1995).
Sorton, Alex; Thomas Walsh. *Bicycle Stress Level as a Tool to Evaluate Urban and Suburban **Bicycle** Compatibility.* Northwestern-University Traffic Institute; Transportation Research Record **1438, 1994.**	Describes the development of a bicycle stress level measure to evaluate the suitability of roadway facilities for bicycling.
Stein, William R. *Pedestrian and Bicycle Modeling in North America's Urban Areas: A Survey of Emerging* Methodologies *and* MPO *Practices.* Thesis: Master of City Planning and Master of Science, Georgia Institute of Technology, March 1996.	Overview of the state of non-motorized modeling at major U.S. **MPOs.** Also includes a literature review of non-motorized user characteristics and preferences and level-of-service measures.
Stein, William R. *Summa y **of** Bicycle Modeling **Efforts** at Portland Metro.* Metro Travel Forecasting Section, Portland, OR, November **22, 1996.**	One-page description of current non-motorized modeling efforts and future plans.
Stutts, Jane C. *Developmenf of a Model Survey for Assessing Levels of **Bicycling** and Walking.* University of North Carolina, Highway Safety Research Center, November 1994.	The purpose of this study is to develop a model survey for states and local communities to use to assess current levels of bicycling and walking. Includes a review and assessment of a variety of existing surveys which either focus on or include non-motorized travel.

Reference	Description
Taylor, Dean and Hani Mahmassani. *Analysis of Stated-Preferences for Intermodal Bicycle-Transit Facilities.* Transportation Research Record 1556, 1996.	A discrete choice model is developed based on a hypothetical-choice stated-preference survey to **assess** preferences for work-trip mode choice (auto, park-and-ride, or bike-and-ride). Facility factors include on-street bicycle facility type, bicycle parking facility type, and access distance to transit. Only relative utilities are reported — the model is not used to predict changes in total mode use as a result of facility changes.
Teichgraber, W. and Ph. Ambrosius. *Potential Demand for Bicycle Traffic in Relation to Existing Bikeway Networks.* In Research for Transport Policies in a Changing World: Proceedings of the World Conference on Transport Research, Hamburg, Germany, April 1983.	The authors develop a measure of quality of bicycle network access to a destination and relate it to the likelihood of using a bicycle to access the destination. The authors find an "S-shaped" relationship, where there is a minimum level of bicycle use even with a poor network and a maximum level which relates to a good network. A slight improvement to a poor network has little effect until a certain minimum standard is achieved. The authors also look at reasons for not bicycling based on survey data, including the influence of route characteristics.
Walsh, Tom. *Bicycle Case Studies: A Review of Planning Guidelines and Design Standards for Bicycle Facilities.* Institute of Transportation Engineers 66th Annual Meeting, pp.. 504, 1996.	Provides a review of planning guidelines and design standards for bicycle facilities.
Weiner, Edward. *Urban Transportation Planning in the United States: An Historical Overview* (Fifth Edition). Publication DOT-T-97-24, U.S. Department of Transportation, 1997.	Reviews the evolution of transportation planning methods in the United States, including the four-step regional travel model approach known as the "Urban Transportation Planning Process."
Weisbrod, Glen and Phil Madsen. *Perception and Preference Models for Motorized and Non-Motorized Travel,* Barton-Aschman Associates, Inc., pp. l-69, August 1979.	The objective of this work was to develop mode perception and preference models based on attitudinal data as obtained from surveys. Modes included auto, transit, walk, and bike. Sophisticated statistical and modeling techniques are used, but the applicability of methods and results to other areas is unclear. Follow-up studies were performed to carry the techniques further into predicting mode choice.

Reference	Description
Wellar, Barry, *Design and Pre-Testing of a Survey Instrument to Measure Pedestrian Levels of Safety and Comfort: A Case Study of the Channelized Cut-Off from Laurier Avenue East to Nicholas Street South, Ottawa, Ontario,* Submitted to the Mobility Services Division, Regional Municipality of Ottawa-Carleton (RMOC), Department of Geography, University of Ottawa, Ottawa, Ontario, July 1995.	The purpose of this study was twofold. First, the study was to gauge the effectiveness of pedestrian improvements to a specific Ottawa intersection. Second, the study was commissioned to create and pre-test a survey instrument for evaluating the concerns of pedestrians in relation to traffic intersections in general. The methodology used was to send researchers to the intersection to conduct tape-recorded surveys of pedestrians. The tape-recorded data was then transcribed to a written survey form. The study concluded that there were concerns about vehicles not yielding to pedestrians. The researchers were very pleased with the effectiveness of this survey method.
Wigan, Marcus, Anthony Richardson and Paris Brunton. *Simplified Estimation of Demand for Non-motorized Trails Using GZS.* Presented at the 1998 Transportation Research Board Annual Meeting, Paper #981203, January 1998.	Describes the application of GIS techniques to compare usage on two non-motorized trails in Australia.
Wilbur Smith Associates. *Non-Motorized Access to Transit: Final Report.* Prepared for Regional Transportation Authority, Chicago, IL, July 1996.	This study estimates the effects on transit mode choice access of various improvements to bicycle and pedestrian facilities in station areas. Methodology is based on estimation of a discrete mode choice model from both revealed-preference and stated-preference survey data.

4.0 Contacts Made

■ 4.1 Consulting Firms

DHV Environment and Infrastructure (Amersfoort, Netherlands)
Hague Consulting Group (Netherlands)
MVA (Manchester, UK)
Sprinkle Consulting Engineers (Lutz, FL)
Steer Davies Gleave (London, UK)

■ 4.2 Countries

Australia
Canada
Chile
Denmark
England
Germany
Israel
Japan
Netherlands
Sweden
United Kingdom

■ 4.3 Research Institutions

Centers for Disease Control (Atlanta, GA)
Georgia Institute of Technology (Atlanta, GA)
Massachusetts Institute of Technology (Cambridge, MA)
Texas Transportation Institute (College Station, TX)
University of California, Berkeley – Institute for Transportation Studies (Berkeley, CA)
Victoria Transport Policy Institute (Victoria, BC)

■ 4.4 Other Organizations

League of American Bicyclists
Rails-to-Trails Conservancy
Sierra Club

■ 4.5 Public Agencies in These Locations

Albany, New York (Capital Region Council of Governments)
California Department of Transportation, Sacramento, CA
Chicago Transit Authority, Chicago, IL
Fort Collins, Colorado
King County, Washington
New York State Department of Transportation
Orlando, Florida
Portland, Oregon
San Diego, California (San Diego Association of Governments)
San Francisco, California (Metropolitan Transportation Commission)
San Luis Obispo, California
State of Oregon

■ 4.6 Individuals

John Abraham, University of Calgary (Calgary, Alberta, Canada)
John Allen (Rust Environment & Infrastructure, Des Moines, IA)
Chris Banister (University of Manchester, UK)
Dan Burden (Walkable Communities, High Springs, FL)
Elizabeth Deakin (University of California – Berkeley)
James Ercolano (New York State Department of Transportation, Albany, NY)
Bruce Epperson (Miami – Dade County MPO)
Ellen Fletcher (City of Portland, OR)
Ann Hershfang (Walk Boston, Boston, MA)
Ralph Hirsch (Ralph B. Hirsch & Associates, Philadelphia, PA)
Michael Jones (Alta Planning and Design, Fairfax, CA)
Bruce Landis (Sprinkle Consulting Engineers, Tampa, FL)
Bill Moritz (University of Washington)
Robert Noland (U.S. Environmental Protection Agency)
Katherine Shriver (University of Texas – Austin)
Marcus Wigan (Oxford Systematics, Heidelberg, Australia)
Jeff Zupan (Regional Plan Association of New York)

4.7 E-Mail Lists

bicycle@yukon.cren.org (general bicycle discussion list)
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